WARREN'S COLLAR WEEVIL IN LODGEPOLE PINE STANDS IN THE KISPIOX FOREST DISTRICT

by

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ABSTRACT

The distribution and abundance of Warren's collar weevil, *Hylobius warreni* Wood (Coleoptera: Curculionidae), was examined in lodgepole pine, *Pinus contorta* var. *latifolia* Engelm., plantations in the Kispiox Forest District in north-central British Columbia. The effect of weevil feeding damage on height growth of dominant and co-dominant trees was also examined. The weevil was found distributed throughout the forest district. All 31 surveyed plantations, ranging in age from 5 years to 16 years, had evidence of larval feeding damage. Weevil-caused mortality ranged from 0-8.8%. The average percentage of sampled trees attacked was 29%. The percentage of trees attacked within a plantation was directly related to plantation age and average tree height. There was not a significant relationship between the thickness of the organic layer above mineral soil and the percentage of trees attacked in the first year of the study. Plantation density had no apparent effect on the percentage of trees attacked. The highest levels of weevil damage were found on circum-mesic, well drained sites in the ICHmc3 biogeoclimatic variant. Plantations established on sites which originally had a pine component appeared to be particularly susceptible to weevil damage. It appears that the collar weevil is not reducing plantations to below minimum stocking levels (< 700 sph).

The populations of the collar weevil found in 2 of the 3 intensively sampled plantations, ranging in age from 13-17 years old, were similar to those reported for naturally regenerated stands of similar age in Alberta. One plantation had populations considerably higher than reported elsewhere. This may have been due to a scarcity of lodgepole pine in the surrounding timber types. The percentage of stems attacked within a diameter class increased proportionally with increasing diameter class, and increasing basal area class. The percentage of the stem circumference girdled increased with increasing root collar diameter and LFH layer depth. The percentage of lodgepole pine attacked within the 3 study sites ranged from 81 % to 92 %. These attack rates were higher than rates reported for naturally regenerated stands. This may have been due to lower tree densities found in planted versus naturally regenerated stands. The high incidence of root collar weevil within the Kispiox Forest District may be related to a man-caused increase in lodgepole pine within the area. This increase has occurred because of the conversion of mature mixed species coniferous stands to lodgepole pine plantations following clearcutting.

Destructively sampled trees indicated that initial weevil attacks within plantations had occurred within the previous 6 years. The time of first attack was uniform within plots indicating that weevils were not dispersing from the stand margin. Results from stem analysis indicated that height growth of weevil damaged trees was not affected in the short term. The long term impacts of sub-lethal multiple weevil attacks and larval damage on height growth are not presently known.

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1.0 INTRODUCTION

The Kispiox Forest District lies within a coastal-interior transition zone in north-central British Columbia. The vegetation exhibits characteristics of a coastal maritime climate and an interior cordilleran climate (Haeussler *et al.* 1985; Meidinger and Pojar 1991). As a result of this transitional climate, the forest cover consists of both coastal and interior tree species. The major tree species include lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), hybrid spruce (*Picea* x *glauca* x *sitchensis* x *engelmannii*), sub-alpine and amabilis fir (*Abies lasiocarpa* (Hook.) Nutt. and *A. amabilis* (Dougl.) Forbes), western hemlock (*Tsuga heterophylla* (Raff.) Sarg.), western redcedar (*Thuja plicata* Donn), trembling aspen (*Populus tremuloides* Michx), and paper birch (*Betula papyrifera* Marsh.). The timber profile in the district has an overabundance of mature/over-mature western hemlock and true fir timber types (>140 years old). More than 80% of the timber inventory consists of these two species (Ministry of Forests 1981). Timber allocation within the district has concentrated on harvesting these timber types in an attempt to minimize losses expected from insects, disease and windfall.

Reforestation of harvested areas is usually achieved by planting spruce and lodgepole pine. Lodgepole pine is planted on drier sites and spruce is planted on wetter sites. The future forest profile will consist of more spruce and pine than exists in the current inventory due to the replacement of hemlock and true fir forests with these two species.

Approximately 12 000 ha of pine have been planted in the Kispiox Forest District as of 1988 (Ministry of Forests 1988). This figure is projected to increase as more areas are harvested. Associated with this increase in the pine component of the profile is a potential increase of insects and diseases which attack lodgepole pine. One such insect is Warren's collar weevil (*Hylobius warreni* Wood (Coleoptera: Curculionidae)).

Ministry of Forests staff, Licensees and silviculture contractors have reported increasing incidence of this insect in lodgepole pine plantations within the Kispiox Forest District in recent years. These increases were of concern because of the abundance of young lodgepole pine plantations within the district. Of particular concern was the potential reduction in stocking due to weevil caused mortality in young stands. As part of the Forest Resources Development Agreement (FRDA I:1985-1990)[1] between the Province and the Federal government, funding was made available to assess the distribution and abundance of Warren's collar weevil in pine plantations within the district. The objective of the project was to provide a better understanding of the relationship between Warren's collar weevil and lodgepole pine plantations. The specific objectives of the study were:

1) To determine the distribution and abundance of Warren's collar weevil in 6 to 16 year old lodgepole pine plantations within the Kispiox Forest District.

(2) To assess the impacts of weevil injury on the development of lodgepole pine stands to the free-growing stage.

(3) To determine if weevil incidence is related to predictable site or stand factors. A hazard map could be produced, using these factors to identify potential problem areas.

(4) To determine timing of the first and subsequent attacks on planted lodgepole pine.

(5) To determine the course of infestations within pine plantations.

(6) To determine the impact of weevil feeding damage on the height growth of lodgepole pine.

1.1 Warren's Collar Weevil

The larvae of Warren's collar weevil feed in the root collar region and on the larger lateral roots of a number of coniferous tree hosts (Furniss and Carolin 1977). Hosts include various species of pines, *Pinus* spp., spruces, *Picea* spp., true firs, *Abies* spp. and tamarack, *Larix laricina* (DuRoi) K.Koch (Warner 1966; Grant 1966). In western North America, the primary host species is lodgepole pine, while white spruce (*Picea glauca* (Moench) Voss) is an alternate and less preferred species (Reid 1952; Stark 1959; Cerezke 1969). Larval feeding results in partial or complete girdling of the major lateral roots and the root collar of the host tree (Reid 1952).

[1] Intensive Forest Management Program - Brushing and Weeding and Pest-control Sub-program

Damage to the root collar region of the tree may cause death either directly or indirectly. Complete girdling of the phloem and cambium tissue at the root collar results in direct mortality while indirect mortality may occur as a result of root decay fungi entering through the larval wound (Warren 1956a; Stark 1959).

Much of the early work on the biology of Warren's collar weevil and its relationship with its host tree species was done in the 1950's and early 1960's in Manitoba, Saskatchewan and Alberta (Warren and Whitney 1951; Whitney 1952; Reid 1952; Warren 1956a-c, 1958; Stark 1959; Whitney 1961). During this period, the taxonomy of the genus was being clarified by a number of researchers (Wood 1957; Warren 1960; Finnegan 1961; Wilson *et al.* 1966; Warner 1966).

Warren's collar weevil was first recognized as a distinct species by Wood (1957). Prior to this, it was identified as *Hypomolyx piceus (*De G.*)*. Wood separated *H. piceus* into two distinct species: *Hylobius warreni* and *Hylobius pinicola* (Couper). The primary basis for the separation was wing form. *H. warreni* has vestigial wings and is a flightless species while *H. pinicola* has functional wings.

The majority of our current knowledge regarding Warren's collar weevil was obtained through the work of Dr. Herb Cerezke in Alberta during the 1960's and early 1970's. He published a number of papers including works on the basic biology of the weevil, its effect on host trees, and its population dynamics in relation to forest management practices (Cerezke 1967, 1969, 1970a-c, 1972, 1973a-b, 1974).

1.2 Biology and Life History

1.2.1 Description

Warren's collar weevil is a relatively large dark brown to blackish beetle with white to pale yellow scales or dots on the elytra (Wood 1957). They range in length from 11.7 mm to 15.1 mm, with the females being slightly larger than the males. The sub-globose eggs are a translucent white and range from 0.5-0.8 mm (Duncan 1986). The larvae are creamy white with a tan coloured head capsule. They pass through six larval instars and a brief pre-pupal stage (Stark 1959). The pupae are approximately 10 mm in length and appear much as the adults do.

1.2.2 Life History

Female weevils deposit eggs in the root collar region of susceptible trees from late June to August (Stark 1959; Cerezke 1969). The egg is deposited in a protective niche which is excavated by the female and covered over with excrement (Warren and Whitney 1951; Cerezke 1969). The larvae emerge an average of 42 days after oviposition (Cerezke 1969).

After emerging, first instar larvae feed randomly on the phloem layer of host trees. However, as the larvae reach the second and third instars feeding becomes more circumferentially oriented and often extends into the cambium (Cerezke 1969). Depending on the time of eclosion, weevil larvae may overwinter as first to fourth instars (Stark 1959; Cerezke 1969). During this time larvae are inactive, and do not commence feeding until the following spring. It is during this second year of larval feeding that the host tree sustains the majority of damage (Stark 1959; Cerezke 1969). Larvae overwinter a second time, usually as fifth or sixth instars.

Larval wounding of the tree base results in the host tree exuding resin at the wounded area. The larvae use the pitch to form a protective feeding gallery or tunnel. These tunnels are composed of a matrix of bark particles, frass and resin, and act as a barrier for the developing larvae, protecting them from potential predators, parasites and dessication (Warren and Whitney 1951; Warren 1956a; Cerezke 1969).

In the spring of the third year larvae feed briefly before constructing a pre-pupal chamber a few centimetres from the base of the tree. This chamber consists of a matrix of resin, frass and bark particles (Stark 1959; Cerezke 1969). The larvae spend a short time in the pre-pupal stage before pupating in June (Cerezke 1969).

Adults emerge after a 4 week pupation period (Cerezke 1969). Adult emergence occurs from late June through August (Warren and Whitney 1951; Stark 1959; Cerezke 1969). The adults can survive for up to four years and they are reproductively mature for at least three years (Cerezke 1970a, 1973). They are nocturnal and emerge from the duff[2] at dusk and either disperse to find suitable host trees or ascend a host to feed in the crown (Cerezke 1969, 1970a). They feed on needles and bark on the upper portion of the branches, and occasionally on the terminal buds (Cerezke 1969; Warren 1956a; Stark 1959). Adults may also feed on the bark of small roots (Warren and Whitney 1951). Adult feeding rarely causes significant damage but may cause the terminal shoots to become twisted and distorted (Cerezke 1969). Dispersal is ambulatory, as Warren's collar weevil has lost the capability for flight (Wood 1957; Warren 1960; Cerezke 1969).

1.3 Effects of Warrren's Collar Weevil at the Tree Level

Warren's collar weevil may affect its host tree in a number of ways. Larval feeding may result in direct tree mortality due to mechanical injury of the root collar (Warren 1956c). Indirect mortality may result through windthrow of attacked trees whose roots have been weakened by larval injury (Cerezke 1969). Indirect mortality may also occur through attack by secondary coniferophagous insects, or fungi, invading a tree weakened by larval damage (Warren and Whitney 1951; Smerlis 1957; Whitney 1961). Weevil damage may also cause growth reductions and changes in the anatomical structure of attacked trees (Cerezke 1969, 1970c, 1972, 1974).

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[2] Organic layer above mineral soil

1.3.1 Mortality

The most evident effect of Warren's collar weevil larval feeding is direct mortality of the host tree. Generally, direct mortality occurs in trees less than 30 years old, and rarely occurs in mature trees (Warren 1956a; Cerezke 1969, 1970a-b, 1974). The reason for this is twofold. First, in younger trees larval feeding tends to be oriented circumferentially around the root collar, whereas in older, larger trees feeding tends to occur in patches and on the larger lateral roots (Cerezke 1970a). The feeding pattern in younger trees causes the flow of nutrients from the crown to the roots to be severed, resulting in root and tree death. In older trees there is often a strip of undamaged bole which continues to supply the roots with nourishment through the undamaged phloem tissue. Second, the more mature roots of older lodgepole pine may be more resistant to weevil feeding than those of younger trees (Cerezke 1970b). There is also evidence that older trees may repair tissue damage caused by root collar weevil larvae (Cerezke 1969).

Larval wounding may pre-dispose trees to attack by secondary organisms. Warren and Whitney (1951) found that larval wounds acted as infection courts for the entrance of the root rot fungi *Armillaria* and *Polyporus* in white spruce. It is these secondary organisms which cause tree death. There is little evidence of any association between root rots, or other decay fungi, and *Hylobius* wounds in lodgepole pine (Stark 1959; Cerezke 1969). Mortality may also be caused by secondary bark beetle colonization of weevil-injured trees. The expenditure of energy by the trees to pitch-out weevils and repair larval wounds may reduce their ability to defend against other tree feeding organisms (Coulson and Witter 1984). Larval feeding may also weaken the trees root system to such a degree that it becomes susceptible to windthrow or snowpress (Duncan 1986).

1.3.2 Anatomical Effects

Weevil injured trees have a number of ways of compensating for tissue injury. They may increase the radial growth of wood on both the girdled and non-girdled portions of the stem to compensate for loss of strength on the wounded portion. This may occur as a "budding" type of growth which seals off the damaged area and increases the area of conductive tissue (Cerezke 1974). The tree may also respond to weevil injury by producing traumatic vertical resin ducts in the growth rings directly above the wounded portion of the stem (Cerezke 1972). This greatly increases the supply of resin to the injured area and may be an attempt by the tree to "pitch-out" the weevil larvae. Although the tree is rarely successful in pitching-out weevils, the flow of resin may be beneficial in coating the wound and sealing off the injured area from the spores of pathogenic fungi. A third mechanism by which the host compensates for weevil injury is the production of adventitious roots above the girdled area (Cerezke 1969). These roots compensate for the loss of conductive tissue below the wound and provide the crown of the tree with a partial supply of water and minerals.

1.3.3 Growth Losses

Partial girdling at the root collar and on lateral roots may lead to significant reductions in both radial and height increment (Cerezke 1969, 1970c, 1974). Losses of 17.16% in mean radial growth and 11.50% in mean height growth were recorded near Robb, Alberta in the second and third years following 50% girdling of lodgepole pine stems (Cerezke 1970a). There were no significant differences in either radial or height growth between attacked and unattacked trees on an ancillary site near Grande Prairie (Cerezke 1970c). Cerezke (1974) artificially girdled the root collars of lodgepole pine trees and found that there was a general decline in height growth with increased circumference of the root collar girdled. Height increment decreased gradually until 60-80% of the root collar circumference had been girdled, after which there was a rapid decrease. However, losses in radial increment did not exceed 5% when compared with controls for a range of girdling classes between 0 and 90%.

1.4 Effects of Warren's Collar Weevil at the Stand Level

Warren's collar weevil infestations have a number of consequences at the stand level. Mortality of individual or groups of trees may result in pockets of Not Satisfactorily Restocked (NSR) areas within a stand (Herring and Coates 1981). Similar patches of windthrown or snowpressed trees may also occur (Duncan 1986).

The primary impact of *H. warreni* at the stand level is growth loss. The cumulative loss of height and/or diameter growth of individual stems must lead to reduced volume production within a stand. Stand level volume loss attributable to root collar weevil damage has not been quantified; however, Cerezke (1969) states that losses to dominant and co-dominant trees may be considerable on good growing sites.

1.5 Control

The strategies for controlling Warren's collar weevil populations may be grouped into two broad classes: chemical controls and silvicultural controls. Chemical controls are implemented after stands have become infested, while silvicultural controls are designed to prevent weevils from invading or re-invading a stand.

1.5.1 Chemical Controls

During the 1950's, ethylene dichloride was effective in killing larvae of Warren's collar weevil and benzene hexachloride (Lindane©) was effective in preventing the re-invasion of previously attacked trees (Warren 1956a). These chemicals were applied directly to the base of infested trees and were extremely toxic. Carbosulfan granular insecticides have been used to control a related *Hylobius* sp. in Europe (Castellano and Marsh 1987). These are also applied directly to the root collar of individual trees. The cost of this labour intensive activity limits their use to intensively managed, high value plantations, and precludes their use in more extensively managed timber production plantations. . The negative impact of such chemicals on non-target organisms must also be considered.

1.5.2 Silvicultural Controls

The first step in implementing silvicultural controls for Warren's collar weevil is identifying high risk stands which are scheduled for harvest. After identification of susceptible stands, it is necessary to develop a prescription which will reduce weevil populations in the subsequent stand. The most effective means of reducing populations is through clearcut harvesting and site preparation (Cerezke 1970a). Infested stands should be clearcut harvested leaving no residual susceptible trees, and site prepared either with scarification or prescribed burning (Cerezke 1969, 1970a). Clearcut harvesting reduces weevil populations by up to 88%, and site preparation results in a further reduction of the residual population by removing or reducing the duff layer, which is critical for larval survival (Cerezke 1973b). Weevil populations in the subsequent stand are reduced accordingly.

There are also silvicultural controls which can be applied after weevils have invaded a stand. These involve screefing the area around the base of infested trees and pruning the lower branches (Warren 1956a; Wilson 1967). Screefing removes the LFH layer at the root collar of host trees thus greatly reducing the weevil habitat. Pruning of the lower branches increases the light and heat around the tree base. This dries out the LFH layer making it unsuitable for oviposition by adult females. As for chemical controls, pruning and screefing may be effective in higher value stands but the high labour costs make them unsuitable on an operational basis for lower value timber production plantations.

1.6 Susceptible Sites

The relationship between forest site type and weevil abundance was first recognized by Warren (1956a-b). He found that damage in spruce stands in Manitoba increased as the average moisture content of the humus layer increased. The highest population of Warren's collar weevil was found on a very wet site characterized by a peat layer over a gleyed soil. In B.C. and Alberta, the weevil is found on drier sites. Stark (1959) found the weevil distributed throughout the forested regions of Alberta, predominantly in the boreal forest. Cerezke (1969, 1970a-b) further refined the weevils site requirements. He found the weevil primarily on moist, rich sites within the boreal region. These were sites with good drainage characteristics, strong soil development and an abundance of herbaceous, moss and shrub species. In Alberta, the weevil shows a definite preference for lodgepole pine stands (Cerezke 1970b). Stands at low elevations have a higher incidence of weevil damage than stands at higher elevations (> 1600m).

In central British Columbia, plantations with the highest incidence of weevil were found on coarse textured, well drained soils, while those found on wet sites with poor drainage were less seriously affected (Herring and Coates 1981). In northwestern B.C., Garbutt (1988) found that weevil damage was confined to trees within one biogeoclimatic variant, the ICHmc3 (i.e. Interior-Cedar-Hemlock, moist, cold- Lower Nass Basin) (Meidinger and Pojar 1991). Susceptible sites within this variant were circum-mesic sites with well drained soils.

Warren's collar weevil is found on sites containing a relatively thick duff layer composed of a mixture of moss and herb species (Cerezke 1970a). There was a strong relationship between the depth of this layer at the tree base and the distribution of weevils within a stand. In general, the number of weevils per tree increased as the thickness of the duff increased (Cerezke 1969). This relationship was stronger as tree size increased.

1.7 Progression of Weevil Infestations with Stand Age

Host trees become susceptible to weevil attack between the ages of 6 and 16 years , when they reach a size of 1-1.5 m tall and 5 cm in diameter at stump height (30 cm) (Warren and Whitney 1951; Reid 1952; Cerezke 1969, 1970a). Warren's collar weevil attacks healthy, vigorous trees and shows a preference for dominant and co-dominants, although intermediate and suppressed trees may also be attacked (Reid 1952). Once weevils become established in a stand they remain there until stand replacement (Warren and Whitney 1951; Reid 1952; Cerezke 1969).

The initial infestation of a regenerating pine stand is believed to originate from surrounding older stands of a susceptible host species (Cerezke 1969). In 15-25 year old lodgepole pine stands in Alberta, Cerezke (1969,1970b) found that infestations spread into pine regeneration at a rate of 10-15 m/year from adjacent infested mature pine. Trees at the periphery of a plantation or naturally regenerating cutblock are attacked first, and the infestation proceeds inward as the population increases. Cerezke (1969) found an increase in attack incidence within stands between the ages of 10 and 60 years. After 60 years, the infestation rate levelled off when up to 90% of trees within a stand had evidence of previous weevil injury. Generally, there is an increase in the number of weevil larvae found on individual trees as stand age increases, however the total population of larvae within a stand during its life remains relatively constant. This is due to natural stand thinning processes which result in the same number of weevils being concentrated on a fewer number of stems (Cerezke 1970c).

The final stage in the cycle of a weevil population occurs when an infested stand is replaced. This can occur either by natural means such as wildfire, or by artificial means such as harvesting. Following clearcutting of infested stands, large increases in weevil populations in surrounding stands have been recorded (Cerezke 1969, 1973b). It is believed that surviving adult weevils migrate from the clearcut into surrounding trees. The adjacent timber, whether mature or immature, provides suitable habitat to maintain populations of the weevil. This "reservoir" population then re-invades the regenerating stand once trees reach a susceptible size.

1.8 Warren's Collar Weevil in British Columbia

In British Columbia, outbreaks of Warren's collar weevil have traditionally been sporadic and localized. Recently, however, populations of the weevil have been on the increase in lodgepole pine stands in the Prince George and Prince Rupert Forest Regions.

The first report of the insect having adverse impacts on forest stands occurred in the Prince George Forest Region (Herring and Coates 1981). Warren's collar weevil was found in 9 of 11 lodgepole pine plantations. The percentage of living trees attacked ranged from 1.2% to 5.0%, and the mortality rate ranged from less than 1% to 8.2%. They estimated an annual increase of between 1.2% and 5.0% in the percentage of trees attacked within a plantation.

Warren's collar weevil has also increased in the Prince Rupert Forest Region in recent years. Specifically, there have been increases in populations of the insect in lodgepole pine plantations near Hazelton (Garbutt 1988). An average of 76% of 4 to 20 year old lodgepole pine trees sampled in five plantations were infested with weevil larvae (Garbutt 1988).

2.0 METHODS

The study was completed over two field seasons: from May 1989 to August 1989 and from May 1990 to August 1990. The first field season concentrated on assessing the distribution and abundance of Warren's collar weevil within the Forest District. The second field season concentrated on assessing the epidemiology of Warren's collar weevil and the potential impact it may have on the height growth of lodgepole pine.

2.1 Study Area

The study was done in the Kispiox Forest District in north-central British Columbia and all survey areas were in the Interior Cedar-Hemlock biogeoclimatic zone, moist cool biogeoclimatic subzone (Meidinger and Pojar 1991). The climate is transitional between coastal and interior influences. It is characterized by warm moist summers, cool wet falls, and cold winters. The average precipitation ranges from 500 - 1200 mm per year. The average daily temperature ranges from -13.9^{o}C for the coldest month to 22.5^{o}C for the warmest month (Haeussler *et al.* 1985).

The majority of sites surveyed over the two year period were within the ICHmc3 variant of the subzone (Meidinger and Pojar 1991) (ICHg3 under the previous classification system (Haeussler *et al.* 1985)). The major tree species include lodgepole pine, hybrid spruce, subalpine fir, amabilis fir, western hemlock, western redcedar, trembling aspen, and paper birch. As the name of the zone implies, hemlock and cedar are the true climatic climax species, however their distribution has been limited by a history of frequent natural fires and human disturbance. Because of this frequent disturbance, the variant is characterized by widespread seral stands of aspen, paper birch, hazelnut (*Corylus cornuta* Marsh.) and other shrubs (Haeussler *et al.* 1985).

2.2 Distribution and Abundance of Warren's Collar Weevil

To assess the distribution and abundance of Warren's collar weevil in the Kispiox Forest District, a representative sample of pine plantations within the district had to be surveyed. The target plantations to survey were 5-to 16-year-old pine stands within the ICHmc3 variant (Meidinger and Pojar 1991), as these plantations were considered to be the most susceptible to colonization by Warren's collar weevil. Additionally, the target was to sample a minimum of 30 pine plantations over the 4 month period.

2.2.1 Selection of sampling method and plot type

Before proceeding with the survey, an appropriate sampling method had to be chosen. Two plot types were selected for evaluation: a 2 m by 25 m strip plot adapted from Fletcher (1986) and a 3.99 m radius circular plot commonly used in B.C. Ministry of Forests silviculture surveys. Both plot types had areas of 50 m^2. A 4 ha area in a Date Creek plantation (Figure 1), known to be infested by Warren's collar weevil (Garbutt 1988), was selected for comparison testing of the 2 plot types. Alternate transects of strip and circular plots were oriented in an East - West direction. Circular plot centres were placed at 25 m intervals while strip plots were oriented sequentially along a transect, with 25 m between transects. The percentage of sample trees with larval damage was determined for each plot type. Dominant and co-dominant lodgepole pine trees with either old or current weevil scarring were considered attacked. The percentage of sample trees attacked was pooled for all plots within each plot type and the two plot types were compared using a Z statistic (Zar 1984).

2.2.2 Sampling intensity and maximum survey area

Logistical constraints necessitated a maximum sampling intensity of 1% (2 plots/ha) for surveyed plantations. This was to ensure that the sampling of the desired number of plantations

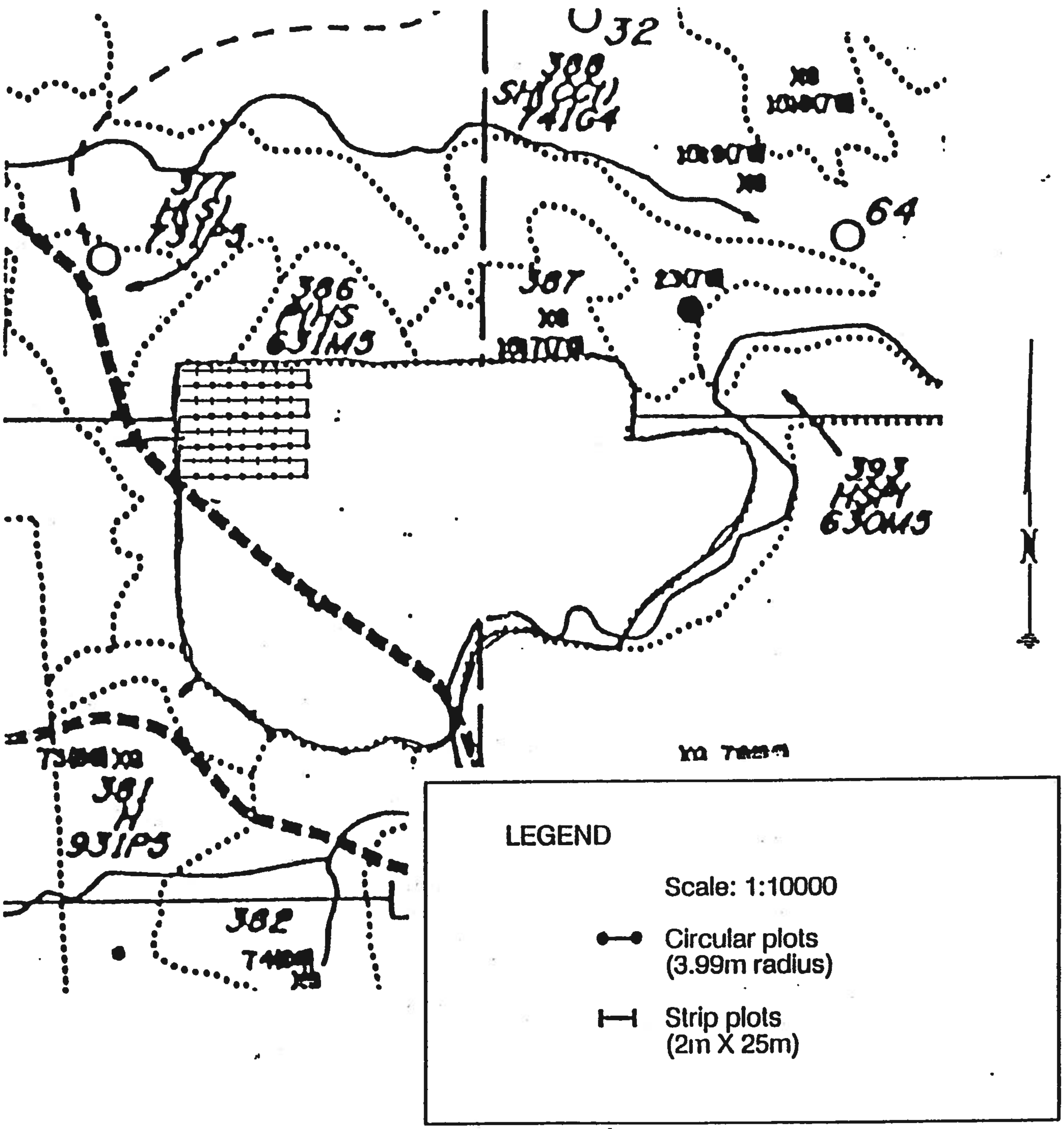

Figure 1. Schematic representation of the layout of two plot types tested for assessing the incidence of *Hylobius warreni* damage in the Kispiox Forest District, Hazelton, B.C., Summer 1989.

was completed within the study timeframe (16 weeks). The maximum area surveyed within any plantation was 50 ha. For plantations greater than 50 ha, an arbitrary 50 ha area was delineated for sampling. Approximately eight weeks into the project it became apparent that due to time, and budget constraints, the minimum number of plantations could not be surveyed using a sampling intensity of 1 %. Therefore, the sampling intensity was reduced to 0.5% of the plantation area (1 plot/ha) for the final 15 plantations.

2.2.3 Plantation Selection

Thirty plantations were selected randomly from a pool of plantations meeting the following criteria: they had to be predominantly pine (> 50% of total stems), they had to be a minimum of 5 years old, and they had to meet the B.C. Ministry of Forests minimum stocking standards (a minimum of 700 well spaced stems per hectare).

2.2.4 Plot information

The following information was collected from each plot:

i). The total # of trees within the plot, classified by species and age class, where 2 broad age classes were established: Layer 1 and layer 2 trees. Layer 1 trees included all species that had seeded in naturally since the time of planting. Layer 2 trees were planted lodgepole pine trees. Layer 2 trees were characterized by the average height and dbh values given for each plantation

ii) The # of dead lodgepole pine (Pl) and spruce (Sx) and the cause of death from visible symptoms.

iii) The # of dying or chlorotic Pl and the cause of stress from visible symptoms.

iv) The # of green healthy looking pine with root collar weevil damage.

v) The # of well-spaced trees per plot based on stem form and spacing (an arbitrary minimum 2 m distance from competing conifers). The maximum # of well-spaced trees/plot was 6.

vi) The # of weevilled (evidence of old or new larval feeding damage) potential well-spaced stems (i.e., meet all requirements of v) and have evidence of weevil damage).

vii) The average LFH depth (organic layer above mineral soil), calculated by taking 4 depth samples every 4th plot. The plot was divided into 4 equal quadrants and a measurement was taken from the centre of each. Sample depths were pooled and the average calculated for each plantation. LFH, as defined in this study, included all organic matter above mineral soil including the moss layer, if present.

Trees were recorded as weevil damaged if they had evidence of new or old attacks. New attacks were distinguished from old attacks by the presence of fresh pitch exudation and/or the presence of larvae.

The average percentage of the stem circumference girdled by weevil larvae and the average number of larvae present per tree for each plantation were also determined for those plantations surveyed at the 0.5% intensity. This was done by arbitrarily selecting the first tree per plot with larval feeding damage and excavating the root collar and larger lateral roots. The percentage of the stem circumference girdled was estimated to the nearest 10%. The total number of larvae per tree was also recorded.

2.2.5 Plot Summaries

Each plantation was summarized in terms of the following attributes:

I) Total trees/ha

ii) Total well-spaced trees/ha

iii) Total trees/ha with weevil damage

iv) Total well-spaced trees/ha[3] with weevil damage

v) % of weevil caused mortality to layer 2 pine

vi) Total # of chlorotic and dead trees due to agents other than weevil

vii) Average tree height

viii) Average diameter at breast height (dbh), where trees were at least 3 m in height.

Average tree height and dbh values for each plantation were determined by measuring a minimum of 30 dominant / co-dominant lodgepole pine trees per plantation.

The age of the dominant/co-dominant trees was assumed to be the same as the plantation age. This was confirmed by sampling a few trees per plantation with an increment borer and also by conducting whorl counts.

2.2.6 Within Plantation Distribution

A 1:10 000 or 1:20 000 scale plot map was produced for each plantation showing the distribution of plots with and without weevilled trees (Figure 2). This was done to determine if there was any apparent stratification of weevil damage within a plantation. This was then

[3] Well-spaced and weevilled well-spaced trees are not necessarily additive. A smaller non-weevilled tree would be tallied as a well-spaced tree even if it was within 2 m of a taller weevilled tree. The weevilled tree would then be tallied as a weevilled well-spaced tree. In the absence of weevil, only one well-spaced tree would have been tallied.

Kispiox Forest District
1989 Warren's collar weevil survey summary

Opening #: 93M032-005

Location: N. of Salmon River

Date surveyed: May 1989

Scale: 1:10000

Total area (ha): 58

Area surveyed (ha): 58

History symbol:

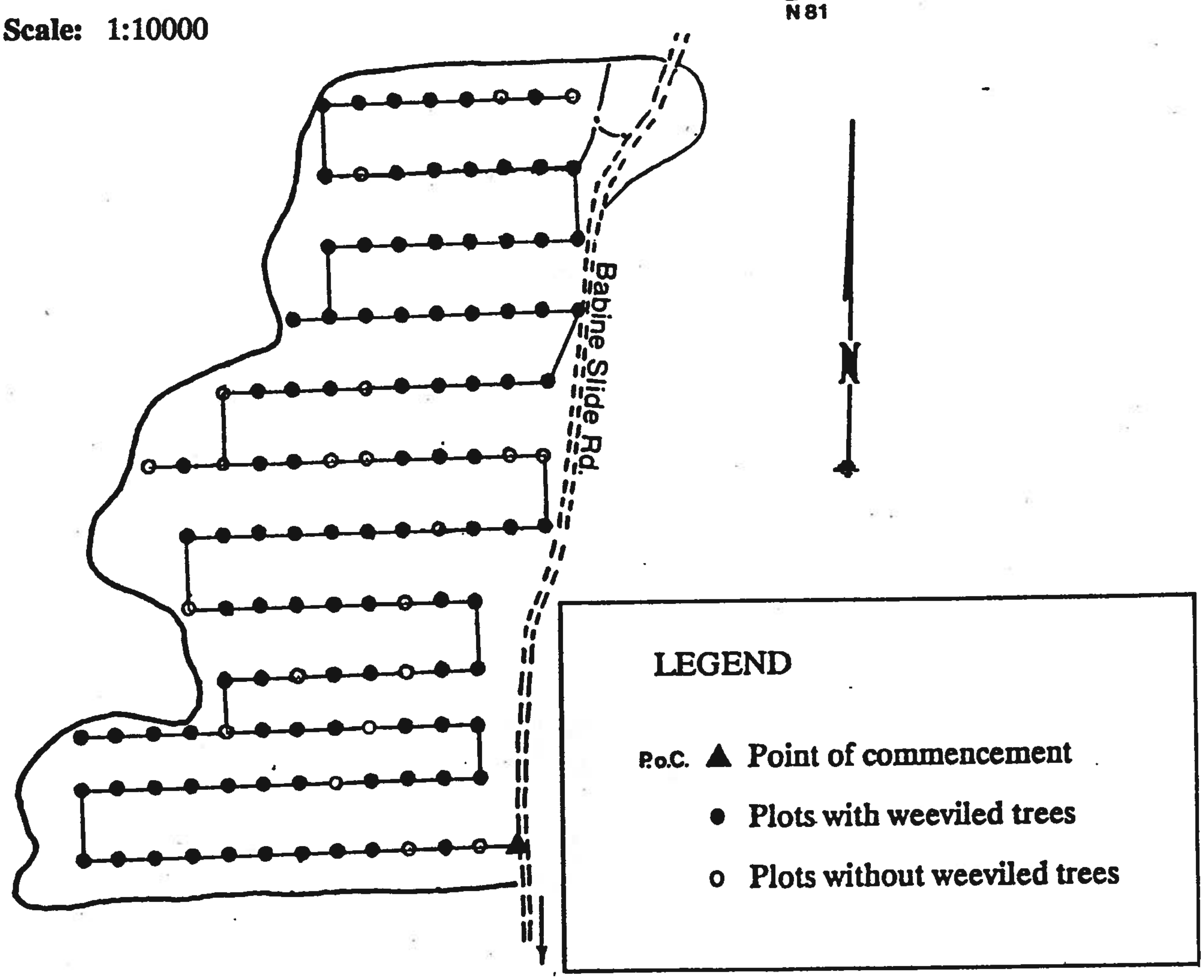

Figure 2. Summary plot map for a plantation surveyed for *Hylobius warreni* damage in the Kispiox Forest District, Hazelton, B.C., Summer 1989.

compared with field information (i.e. plot notes) to determine the pattern of weevil attack within the sampled area.

2.2.7 Historical Information

The B.C. Ministry of Forests history record system provided historical background information on surveyed plantations. This included information on original stand type, site preparation method, plantation establishment and, in some cases, ecosystem classification. This information was then used to determine if site history is useful in predicting weevil abundance within plantations.

2.2.8 Survey Summary

After data compilation was completed for all plantations, simple linear regression (Zar 1984) was used to determine the relationship between percentage of sample pine attacked, and plantation age, tree height, tree density and LFH depth. Regression analysis was done using MIDAS (Fox and Guire 1976) on the University of British Columbia computing services network.

2.3 Height Growth and Dispersal Study

2.3.1 Study Locations

The study was replicated at three locations within the Kispiox Forest District: Date Creek, Mosquito Flats, and Shandilla Creek (Figure 3). These locations had been surveyed in 1989 as part of the distribution study and were known to support weevil infestations. All plantations were surveyed from May through August 1990. All plantations were within the ICHmc3 biogeoclimatic variant (Meidinger and Pojar 1991).

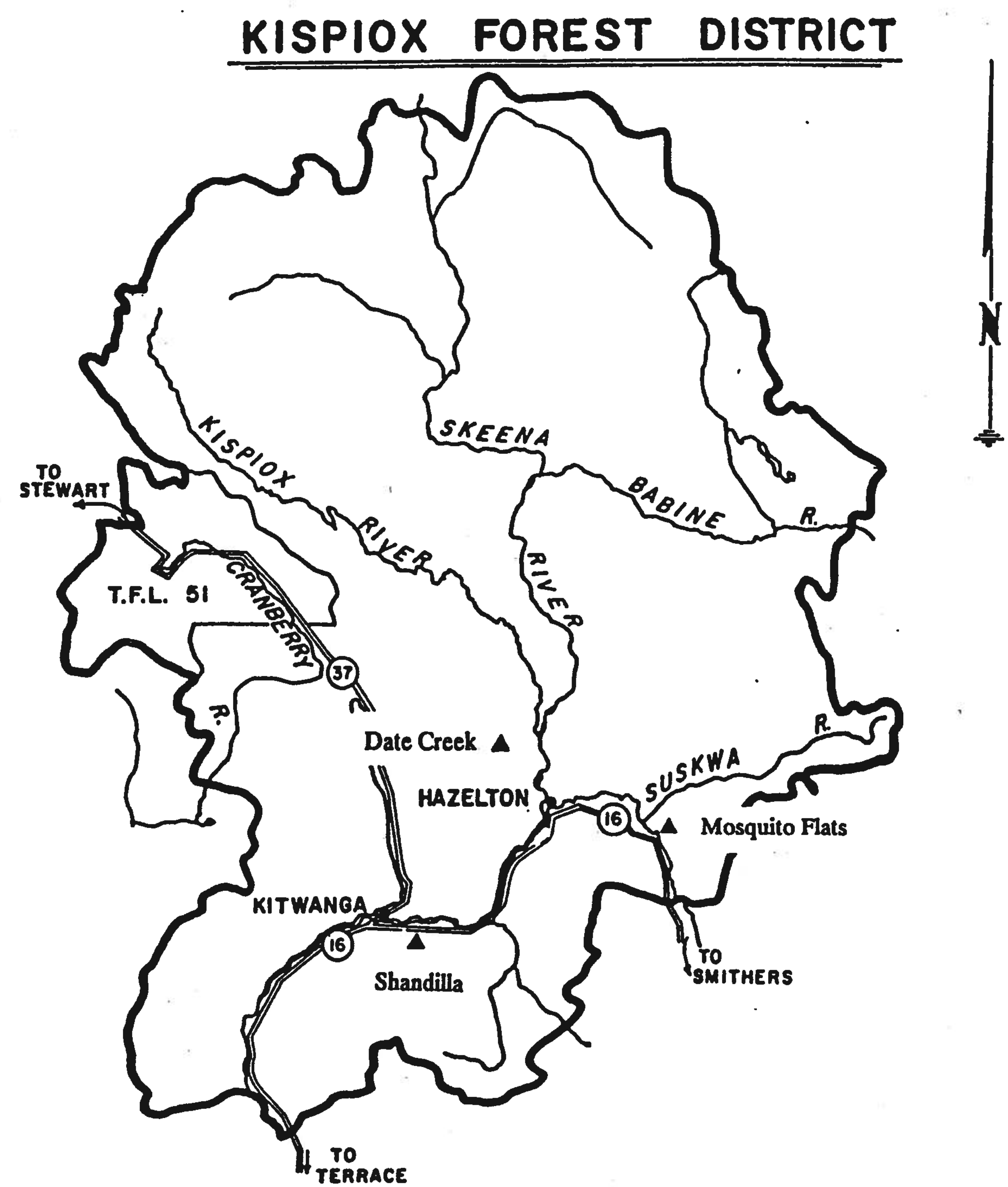

Figure 3. *Hylobius warreni* study sites in the Kispiox Forest District, Summer 1990

2.3.1.1 Date Creek

This opening was clearcut logged in 1975 and was spot burned and planted in 1976. The original stand type was spruce-hemlock. The elevation is 457 m, the average slope is 20%, and it has a southerly aspect. Stand density was estimated at 5455 sph in 1989 (first year of study), however a large portion of this density was relatively small natural seedlings which had ingressed since planting. Lodgepole pine is the major species, while spruce is a minor component on wetter microsites. Natural regeneration included western redcedar, western hemlock and true fir. The 1989 survey found 45% of sampled trees had evidence of weevil feeding.

2.3.1.2 Mosquito Flats

This opening was clearcut logged and broadcast burned in 1972, and planted in 1973. The original stand type was hemlock-pine. The plantation was manually weeded in 1985 and fertilized in the fall of 1989. The elevation is 487 m, the average slope is 10-20%, and the aspect west. Stand density was estimated at 1054 sph in 1989 (first year of study). Lodgepole pine is the major species, with spruce making up a minor component. Natural regeneration included western hemlock, western redcedar and some true fir. The 1989 survey found 84% of sampled trees had evidence of weevil feeding.

2.3.1.3 Shandilla Creek

This opening was clearcut logged in 1968, burned in 1969, 1970 and 1972, and planted in 1973. The original stand type was hemlock-spruce. This plantation was fertilized in the fall of 1989. The elevation is 381m, the average slope is 50%, and the aspect north. Stand density was estimated at 3095 sph in 1989 (first year of study). Lodgepole pine is the major species, with spruce making up a minor component. Natural regeneration includes western hemlock and western redcedar. The 1989 survey found 55% of sampled trees had evidence of weevil feeding.

2.3.2 Sampling Methodology

A single rectangular plot 20 m wide and 150 m long (200 m long in the Date Creek plantation) extended perpendicularly from the stand margin into the plantation. The point of commencement for the plot was chosen for ease of location and proximity to mature timber (preferably pine). Plot boundaries were located using a compass and 50 m nylon chain, and were marked with flagging tape. The four corners of the plot were marked with wooden stakes and the P.O.C. was marked with a metal tag.

Within each plot all pine and spruce trees were permanently numbered and tagged and sampled for the following parameters:

i) Organic layer depth (LFH) at the root collar of all sampled trees. Two measurements were taken on opposite sides of the tree and LFH depth was recorded as the mean of these two values. Measurement location was arbitrary. Notes were also recorded on the composition of the LFH layer at the tree base and within the plantation, in general.

ii) Root collar diameter.

iii) Number and age of weevil life stages present.

iv) Percentage of root collar circumference girdled for attacked trees. Girdles were classed as new or old: new attacks had fresh resin and larvae were present, while old attacks were characterized by hard, whitish resin deposits.

vi) Presence of other damaging organisms.

2.3.3 Height Growth Study

2.3.3.1 Tree Selection

After all trees were sampled and damage assessments were completed, the trees were grouped into four girdling classes according to the amount of the root collar circumference girdled: 0%, 1-50%, 51-80% and 81-99% of the root collar girdled. The categories for the Date Creek plantation were 0%, 1-50%, 51-70%, and 71-99%. The girdling classes were changed for the former two plantations in mid-project because it was felt that growth losses may become more evident after 80% of the root collar has been girdled (Cerezke 1974). The five largest diameter trees in each class were selected for stem analysis.

2.3.3.2 Stem Analysis

Each of the selected trees was felled and the internodal growth over the life of the tree was measured. Wooden discs were removed from the root collar and the years of weevil attack were assessed using a starch staining method developed by Cerezke (1972). When injury to the cambium of the tree occurs, the tree responds by producing traumatic resin ducts. These traumatic ducts show up as tangential bands in the annual rings in the years in which the damage occurs, and can be used to determine the time of the injury. Using this method and the presence of old weevil feeding scars, it was possible to determine when the tree was attacked.

2.3.3.3 Statistical Analysis

Analysis of variance (one-way) was used to compare girdling classes for differences in root collar diameter, breast height diameter, and annual height increment. A Student-Newman-Keuls test was used to test for significant differences among means for these parameters (Zar 1984). Annual height increments from 1979 to 1989 were tested for significant differences between girdling classes for the Mosquito Flats and Shandilla plantations. Height increments between 1980 and 1989 were tested for significant differences between classes in the Date Creek plantation. Pre-1979 height increments for Mosquito Flats and Shandilla, and pre-1980 height increments for Date Creek were excluded from analysis to ensure that growth was relatively linear from year to year. Reliability of height measurements below breast height was somewhat suspect.

3.0 RESULTS

3.1 Distribution and Abundance of Warren's Collar Weevil

3.1.1 Selection of plot type

There was no significant difference in the percentage of sampled trees with weevil damage between the 2 plot types ($Z=0.176$; $p > 0.05$). In strip plots, 46.3% of sampled stems had evidence of weevil feeding. In circular plots, 45.2% of sampled stems had evidence of weevil feeding.

3.1.2 Plantation distribution

Surveyed plantations were distributed throughout the Kispiox Forest District (Figure 4). Plantations ranged in age from 5 to 16 years (Table 1, Figure 5). The average age of surveyed plantations was 9 years. Plantation size ranged from 4 ha to 107 ha. The average plantation size was 58 ha. The average area surveyed was 40 ha.

3.1.3 Plantation summaries

The average % of sampled pine with Warren's collar weevil larval damage was 29 % (S.D.=26%; Range:0-100%) (Table 1). The average % of sampled spruce with larval damage was 1.4% (S.D.= 3.5%; Range: 0-15%). Weevil caused mortality was low in most plantations, averaging 1.5% (S.D.=1.9%; Range:0-8.8%).

The average percentage of the circumference of the root collar girdled of sampled trees for the final 15 plantations was 50% (S.D.=32%, n=107) and the average number of larvae per girdled tree was 0.33 (S.D.=0.49, n=107).

In most cases there were sufficient unattacked well spaced trees to maintain plantations at minimum stocking (20 of 31 plantations > 700 stems/ha)(Table 1). Four of the eleven plantations which were below minimum stocking had less than 600 stems/ha.

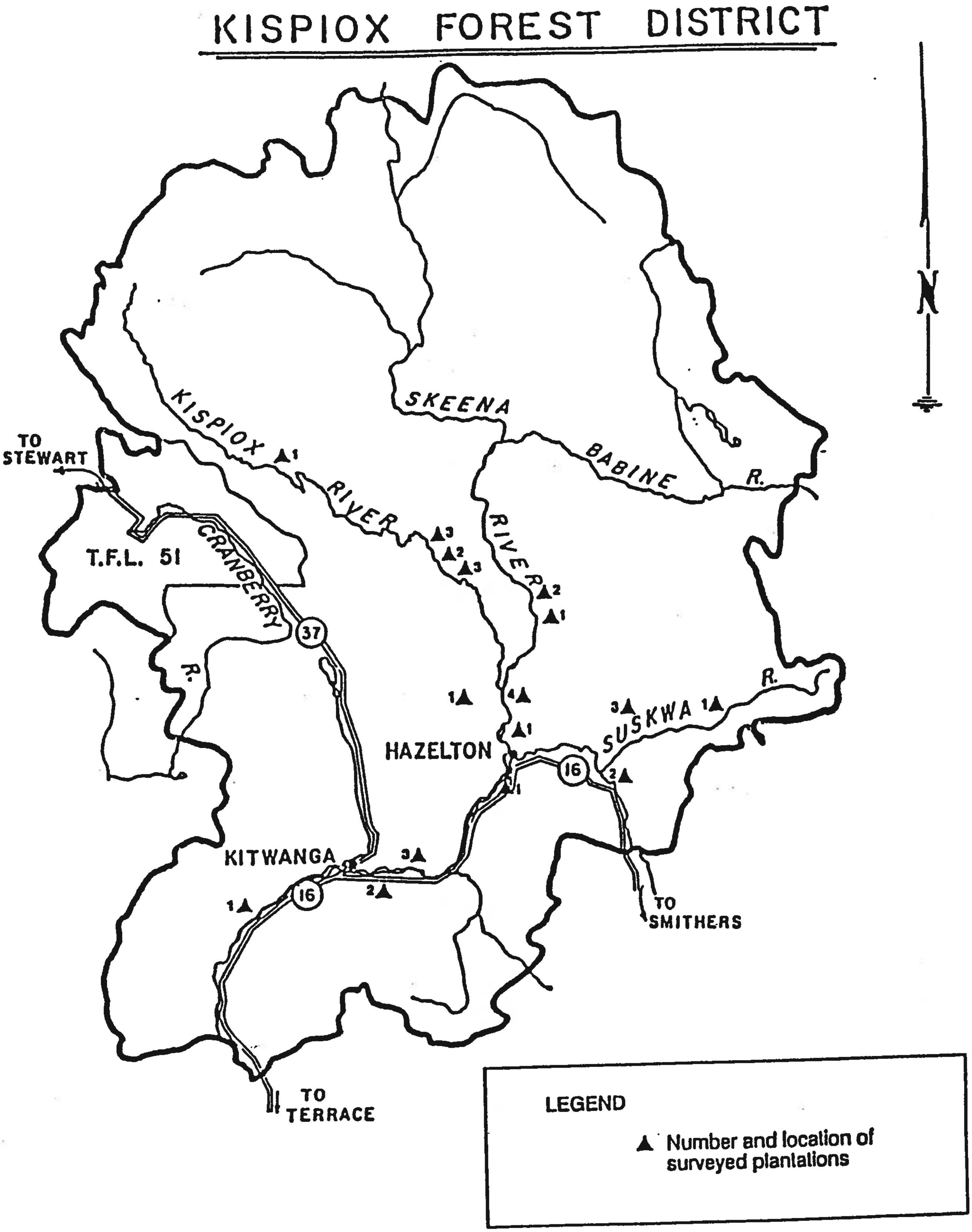

Figure 4. The distribution of pine plantations surveyed for *Hylobius warreni* damage in the Kispiox Forest District, Hazelton, B.C., Summer 1989

Table 1. Summary data for plantations surveyed for *Hylobius warreni* in the Kispiox Forest District, Hazelton B.C., Summer 1989.

Location	Opening #	Plantation Age	Site Preparation	Ecosystem Classification	Original Stand Type	Elevation (m)	Slope (%)	Aspect	Soil Texture	LFH (cm)	Area (ha)	Sampling Intensity (%)	%[1] Weevilled	% Weevil Mortality	Well Spaced Stems/ha	Weevilled[2] Well Spaced/ha	Total Trees/ ha	Tree Height (m)	DBH (cm)
Shandilla	93M001-009	16	Broadcast burn	ICHg3.01/09	HSx	381	50	N	SL	7	50	1	55	1.1	608	492	3095	7.04	10.1
W.of Skeenax	93M001-013	16	Broadcast burn	ICHg2.01	HCw	457	20	N	-	7	50	1	34	0.5	614	214	2894	6.46	8.1
Nash Y	93M011-041	16	Broadcast burn	ICHg3.01/.09	PlH	549	10	SE	SL	4	30	1	75	1.0	240	540	2860	7.32	10.5
Suskwa R.	93M024-007	13	Broadcast burn	ICHg2-3	CwB	610	15	S	-	15	50	1	27	0.3	726	202	1750	6.37	9.3
Suskwa R.	93M024-016	16	Broadcast burn	ICHg3.01	HCw	457	20	N	-	12	46	1	71	1.1	428	405	2959	7.45	9.5
Mosquito Flat	93M024-025	16	Broadcast burn	ICHg3.01	HPl	487	10	W	-	6	38	1	84	1.3	177	564	1054	5.07	10.3
Robinson Lk.	93M033-005	16	Broadcast burn	ICHg3.03a	HB	884	20	N	-	11	14	1	43	0	600	250	1864	6.89	10.1
Nash Y	93M011-047	10	Spotburn	ICHg3.01	PlSx	549	10	SE	SL	6	33	1	23	1.2	1030	272	6520	3.60	4.7
Seely Lk.	93M022-019	13	Spotburn	ICHg3	PlSx	450	20	S	-	5	50	0.5	35	0.1	440	464	6944	4.09	4.5
Suskwa R.	93M024-005	10	Spotburn	ICHg3.01	PlH	762	10	S	SiL	8	43	1	34	2.2	825	138	2666	4.16	5.7
N.Salmon R.	93M032-005	8	Spotburn	ICHg3.08	Pl	305	0	F	SiL	7	58	1	42	1.4	361	357	2730	4.08	4.3
Utsun Cr.	93M042-007	7	Spotburn	ICHg3.01	HCw	534	10	V	SL/LS	7	50	1	6	6.3	1024	28	9132	3.31	4.4
Date Cr.	93M042-026	13	Spotburn	ICHg3.01	SxHw	457	20	S	-	5	4	8	45	2.4	710	-	5455	-	-
N.Kline Lk.	93M051-002	7	Spotburn	ICHg3.01/02/03	SxPl	390	0	F	-	8	50	0.5	19	0	712	12	1920	2.57	-
Murder Cr.	93M051-006	6	Spotburn	ICHg3.01a	HB	580	15	SW	-	7	42	0.5	12	1.6	812	76	3468	2.47	-
LOT 3020	93M051-014	12	Spotburn	ICHg3.01	PlAt	549	30	W	SL	4	50	0.5	23	0.3	648	316	6208	3.86	5.4
Cullon Cr.	93M061-016	6	Spotburn	ICHg3.01	HPl	500	10	F	CL	7	50	0.5	6	0.7	688	24	1500	2.08	-
Cullon Cr.	93M061-030	6	Spotburn	ICHg2.01	HSx	450	20	S	L/CL	7	30	0.5	5	0	900	17	2550	2.14	-
Ironside Cr.	103P060-002	5	Spotburn	ICHg3.09b	SxPl	450	10	SW	L	5	17	0.5	100[c]	2	829	14	1856	1.64	-
Ironside Cr.	103P070-010	6	Spotburn	ICHg3.01/03	SxB	450	15	SE	SiCL	7	50	0.5	8	3.6	896	28	2688	1.86	-
Ironside Cr.	103P070-023	8	Spotburn	ICHg3.01/03	PlSx	425	20	V	SL	4	50	0.5	6	0	1012	36	3484	2.01	-
Sterritt Cr.	93M052-023	5	Scarified	ICHg3.01/03	H	450	15	SW	L	7	36	0.5	4	1.4	971	5	5060	1.97	-
Salmon R.	93M032-011	5	Scarified	ICHg3.01/09	SxPl	300	0	F	LS	5	28	0.5	22	6.8	856	0	2471	2.16	-
Salmon R.	93M032-014	5	Scarified	ICHg3.09	PlSx	300	15	NW	SiCL	6	47	1	34	6.0	763	167	4637	1.67	-
Natlan Cr.	93M034-005	5	Scarified	ICHg2.04	HB	762	20	S	C	13	50	1	3	0	888	2	2984	0.95	-
5 m.Nash Y	93M011-045	9	Nil	ICHg3.01/02	PlSx	450	10	SW	-	6	50	1	12	0.3	902	180	3740	-	-
Luno Cr.	93M014-062	5	Nil	ICHg3.01/03	SPl	400	20	W	Cl/SL	7	22	1	17	4.0	823	45	2173	1.74	-
Swan Rd.	93M032-007	5	Nil	ICHg3.01/03	PlAt	275	15	V	SL-L	6	4	0.5	31	0	800	400	2850	1.75	-
Sterritt Cr.	93M052-010	5	Nil	ICHg3.01	SxCw	450	5	F	C/LS	6	49	0.5	3	1	778	5	1454	2.00	-
7 Sisters	103P009-011	6	Nil	ICHg2.01/04	HSx	460	15	N	SL	6	39	0.5	0	0	856	0	3959	1.59	-
Nangeese R.	103P079-005	6	Nil	ICHg3.01	SB	550	0	F	LS	6	14	0.5	6	0	614	143	1700	1.85	-

a. Expressed as % of weevilled layer 2 pine(characterized by average height and dbh values).

b. Meet all requirements of a well spaced tree with the exception of weevil damage (i.e. good form and spacing).

c. n=3 trees.

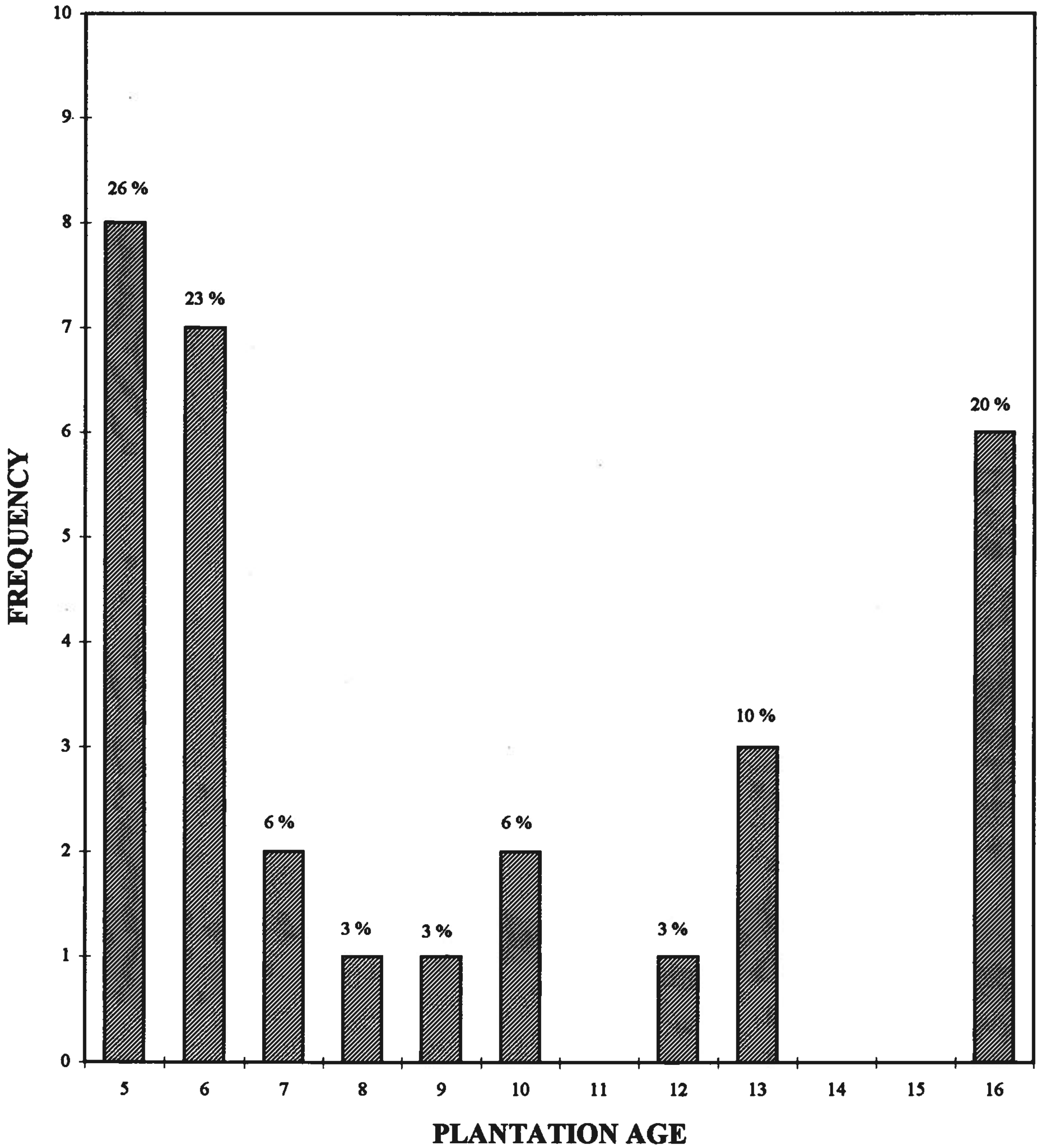

Figure 5. Age distribution of pine plantations surveyed for *Hylobius warreni* damage, Kispiox Forest District, Hazelton, B.C., Summer 1989.

3.1.4 Weevil incidence in relation to site and stand factors

The incidence of root collar weevil damaged trees was greater in older plantations than younger plantations (Table 1, Figure 6). The average percent of trees attacked in plantations older than 10 years was 48%, but was only 14% in plantations younger than 10 years. The percentage of trees damaged by Warren's collar weevil also increased with increasing average tree height (Figure 7). Average tree height increased with increasing plantation age (Tree height = 0.45 x Plantation age - 0.51, $R^2 = 0.91$, SE = 0.64, $p< 0.05$).

There was no apparent relationship between the percentage of trees with weevil damage and the total number of stems/ha (sph) (Figure 8). Surveyed plantations ranged from 1054 sph to 9132 sph.

There was not a good relationship between average LFH layer depth and the percentage of pine with root collar weevil damage (Figure 9). The LFH layer depth varied from 3-15 cm.

Burning or scarification did not reduce the abundance of weevils (Table 1). The average percentage of trees with larval damage was 55.7% on broadcast burn blocks, 26% on spotburn blocks, 15.8% on scarified blocks and 13% on blocks with no site preparation treatment. The average age of plantations with each treatment type was 16 years for broadcast burned blocks, 8 years for spotburn blocks, 6 years for no treatment and 5 years for scarified blocks. Two Salmon River plantations which were scarified had high levels of weevil damage (Table 1; 93M032-011 and 93M032-014).

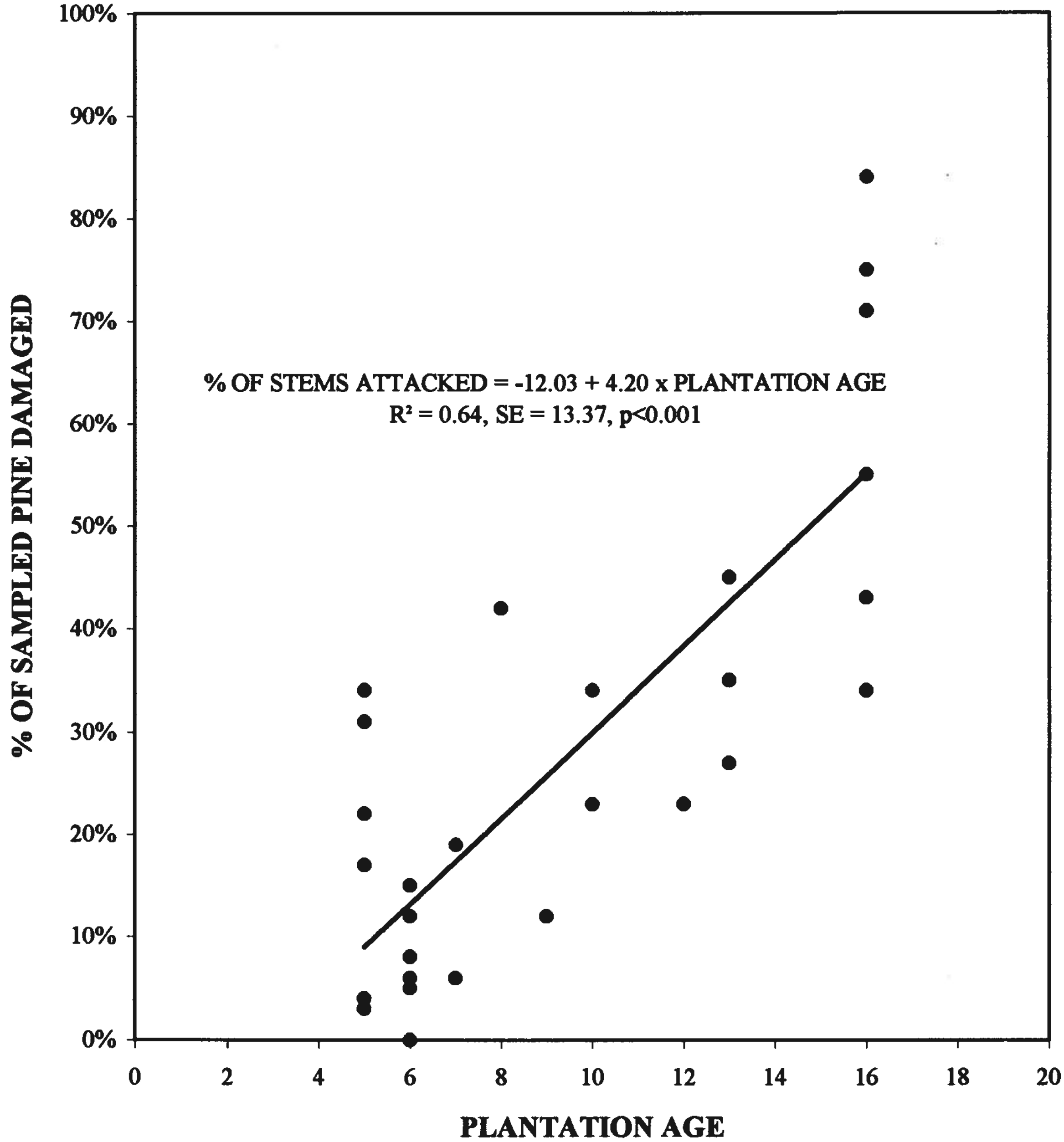

Figure 6. Percentage of sampled Lodgepole pine with *Hylobius warreni* damage in relation to plantation age in the Kispiox Forest District, Hazelton, B.C., Summer 1989.

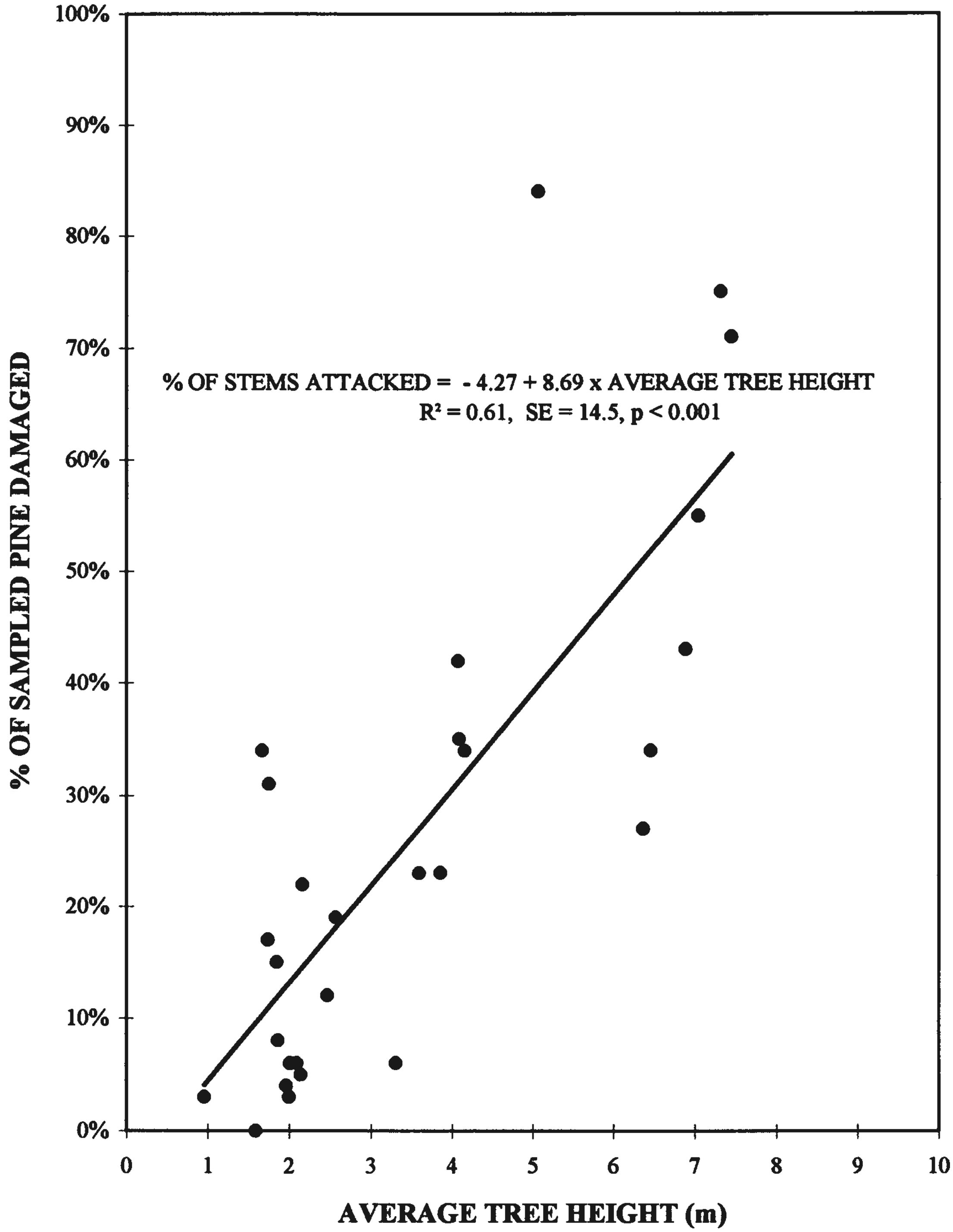

Figure 7. Percentage of sampled Lodgepole pine with *Hylobius warreni* damage in relation to average tree height in the Kispiox Forest District, Hazelton, B.C., Summer 1989.

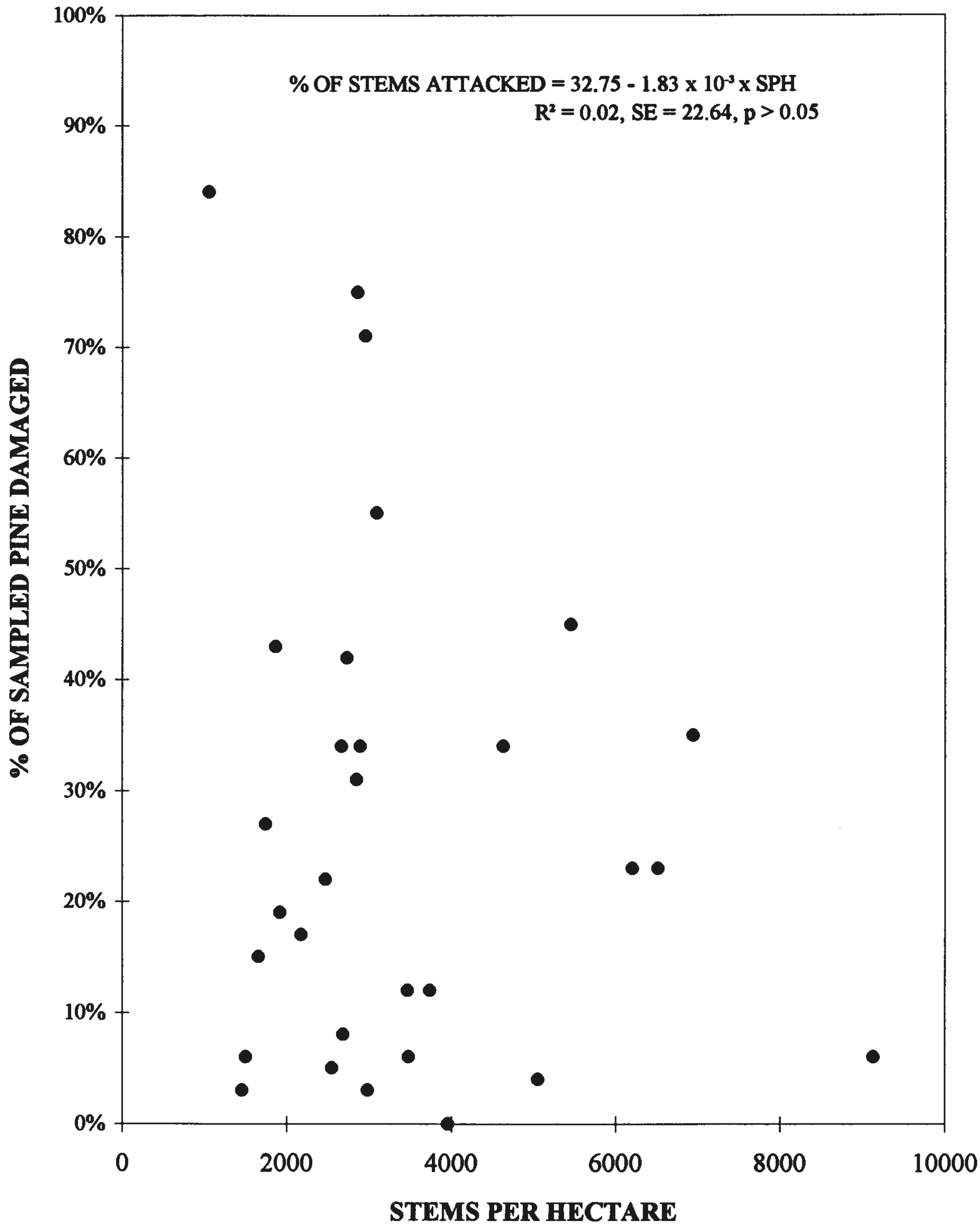

Figure 8. Percentage of sampled Lodgepole pine with *Hylobius warreni* damage in relation to plantation density in the Kispiox Forest District, Hazelton, B.C., Summer 1989.

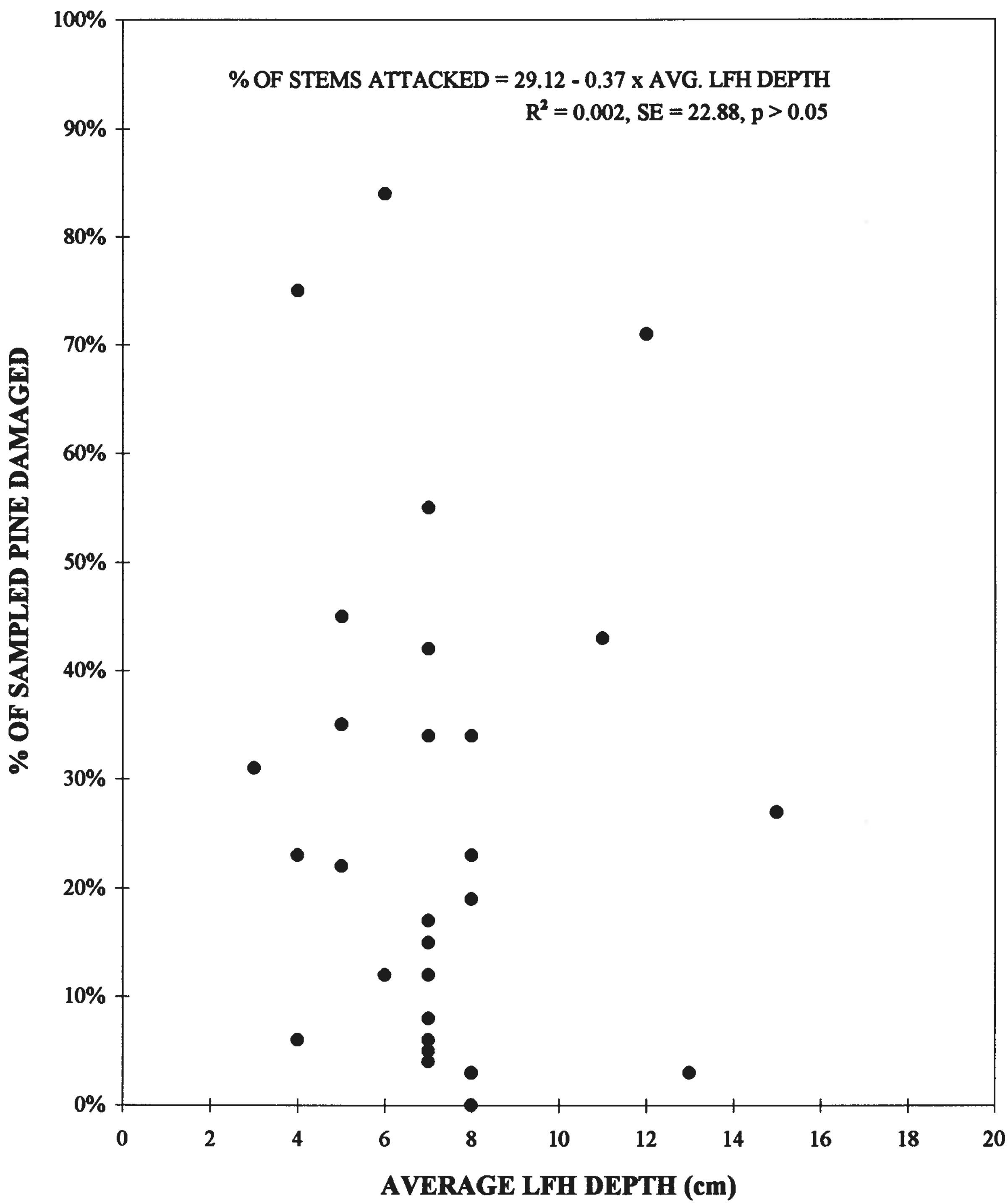

Figure 9. Percentage of sampled Lodgepole pine with *Hylobius warreni* damage in relation to average organic matter layer depth in the Kispiox Forest District, Hazelton, B.C., Summer 1989.

Eighty-seven percent of sampled plantations were within the ICHg3 subzone. Of these 87% , 85% were within the ICHg3.01 ecosystem association. One hundred percent of plantations surveyed were within the ICHmc3 biogeoclimatic variant. There was a wide range of weevil incidence within all sampled plantations irrespective of ecosystem association. In general, weevil damage was prevalent on circum-mesic well drained sites. Within the Kispiox District this includes the ICHg3. 01/03/08/and 09 ecosystem associations. Under the new classification system susceptible site series would include the ICHmc3/01/04/05.

Plantations on sites which had a pine component prior to harvest, or were adjacent to standing mature pine, appeared to be most susceptible to weevil damage (Table 1). The average percentage of stems with weevil attacks in plantations established on sites which previously had a Pl component in the inventory was 31%; the average for plantations on sites with Pl as a minor component (or no component) in the previous stand was 20%. However, some plantations which had minor components of Pl prior to harvest had relatively high rates of weevil damage (Table 1).

There was no indication that elevation, slope, or aspect had an impact on weevil abundance. The elevational range of the plantations varied from 300 m to 884 m (average:487 m; S.D.:137 m) (Table 1). The slopes on surveyed plantations ranged from 0-50% (average:15%; S.D.:9.9%).

3.1.5 Within plantation distribution.

Weevil attack pattern was not stratified within a plantation. Weevil damaged trees were either randomly distributed within sampled plantations or the distribution was clumped in no particular pattern.

3.1.6 Within district distribution.

Root collar weevil was found in all surveyed plantations within the Kispiox Forest District (Table 1). The Seven Sisters plantation (103P009-011) had a 0 % infestation rate based on our survey data; however, weevil damaged trees were found outside of the plot boundaries. High weevil attack rates were found in all older pine plantations within the district. Plantations with particularly high levels of infestation were found in the Suskwa River, Nash Y and Shandilla areas of the district. Salmon River plantations, which were considerably younger, were also heavily infested. The upper Kispiox drainage (Sterritt Cr., Ironside Cr., Cullen Cr.) had relatively low levels of weevil damage.

3.2 Height Growth and Dispersal Study

3.2.1 Plot summaries

3.2.1.1 Date Creek

Seventy percent of all sampled trees had evidence of weevil damage (Table 2). Eighty-one percent of all sampled lodgepole pine had evidence of attack, while 37% of all sampled spruce had evidence of attack. All dead pine appeared to have died as a result of weevil feeding as indicated by root collars which were completely girdled. The total mortality attributed to Warren's collar weevil was only 3% of sampled trees (Table 2).

The average diameter of attacked pine was 7.9 cm (Table 3). The average number of larvae per tree was 1.2. The number of weevils per hectare, based on the average number of weevils per tree and the estimated stems per hectare, was 850. The percentage of trees attacked within a diameter class increased with increasing diameter class (Figure 10). There was a significant relationship between root collar diameter and percentage of stem girdled (Figure 11). The regression of percent of stem girdled on LFH depth was also significant (Figure 12).

Table 2. Number and percentage of sample trees attacked by *Hylobius warreni*, by host species, at Date Creek in the Kispiox Forest District, Summer 1990.

	Lodgepole pine			**Spruce**	
	Attacked	**Unattacked**	**Dead**	**Attacked**	**Unattacked**
Total Trees	265	66	9	18	49
Stems per hectare	663	165	23	45	123
% of Species Total	78	19	3	37	63

Table 3. Population estimates of *Hylobius warreni* and characteristics of attacked lodgepole pine trees at Date Creek in the Kispiox Forest District, Summer 1990.

	RCD[a] (cm)	% GIRDLE[b]	**Weevil Numbers per Tree**				LFH[f] (cm)
			1ST YEAR[c]	2ND YEAR[d]	3RD YEAR[e]	TOTAL	
AVERAGE	7.9	34	0.5	0.3	0.5	1.2	7
S.D.	3.9	33	1.0	0.6	1.0	0.9	4

a. Root Collar Diameter

b. % of root collar circumference girdled

c. Larvae hatched from the current years eggs (1990)

d. Larvae hatched from 1989 eggs.

e. Larvae and pupae from 1988 eggs

f. Average depth of organic layer above mineral soil.

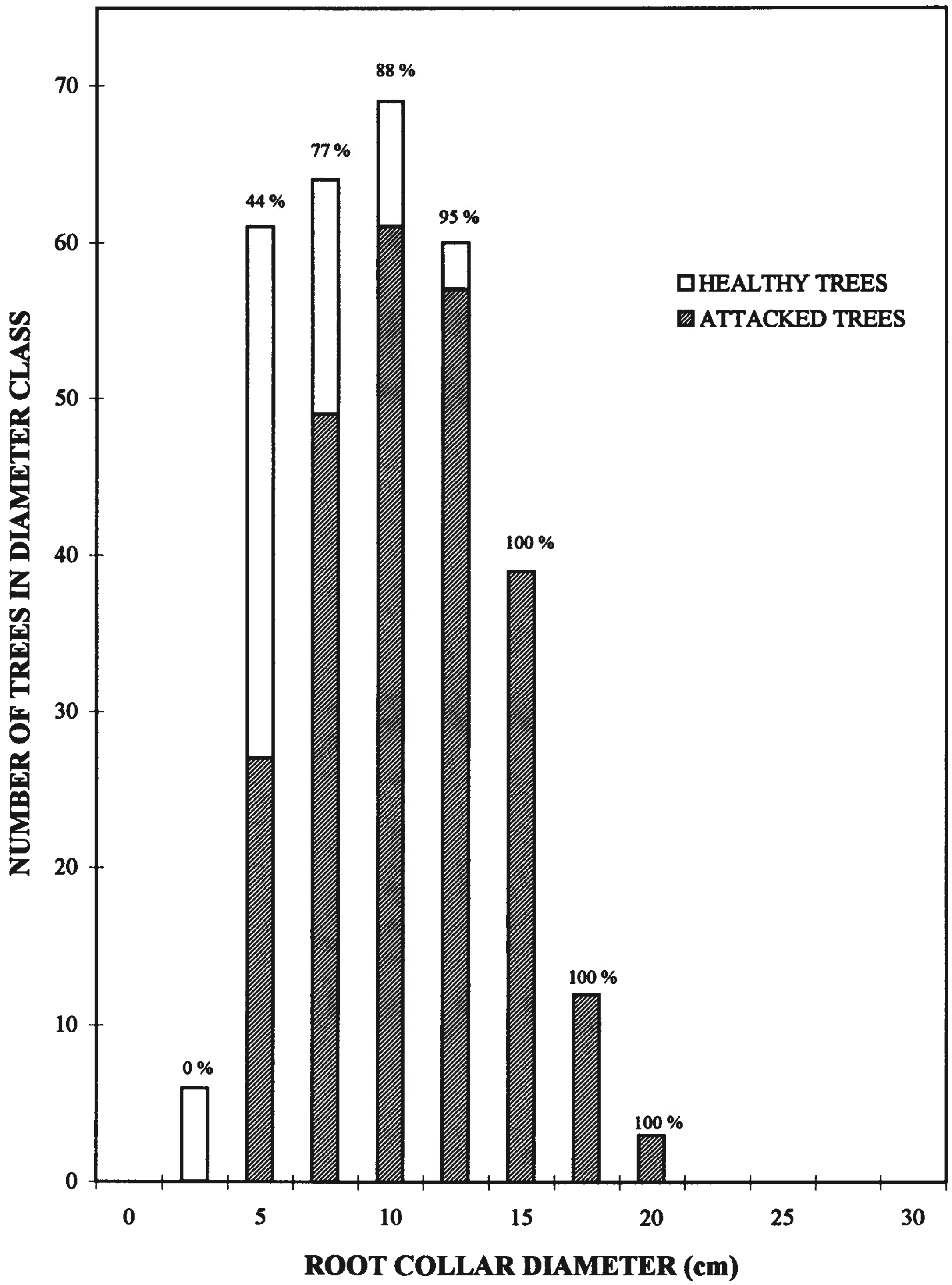

Figure 10. Diameter distribution of sampled Lodgepole pine trees and proportion attacked by *Hylobius warreni* at Date Creek in the Kispiox Forest District, Summer 1990.

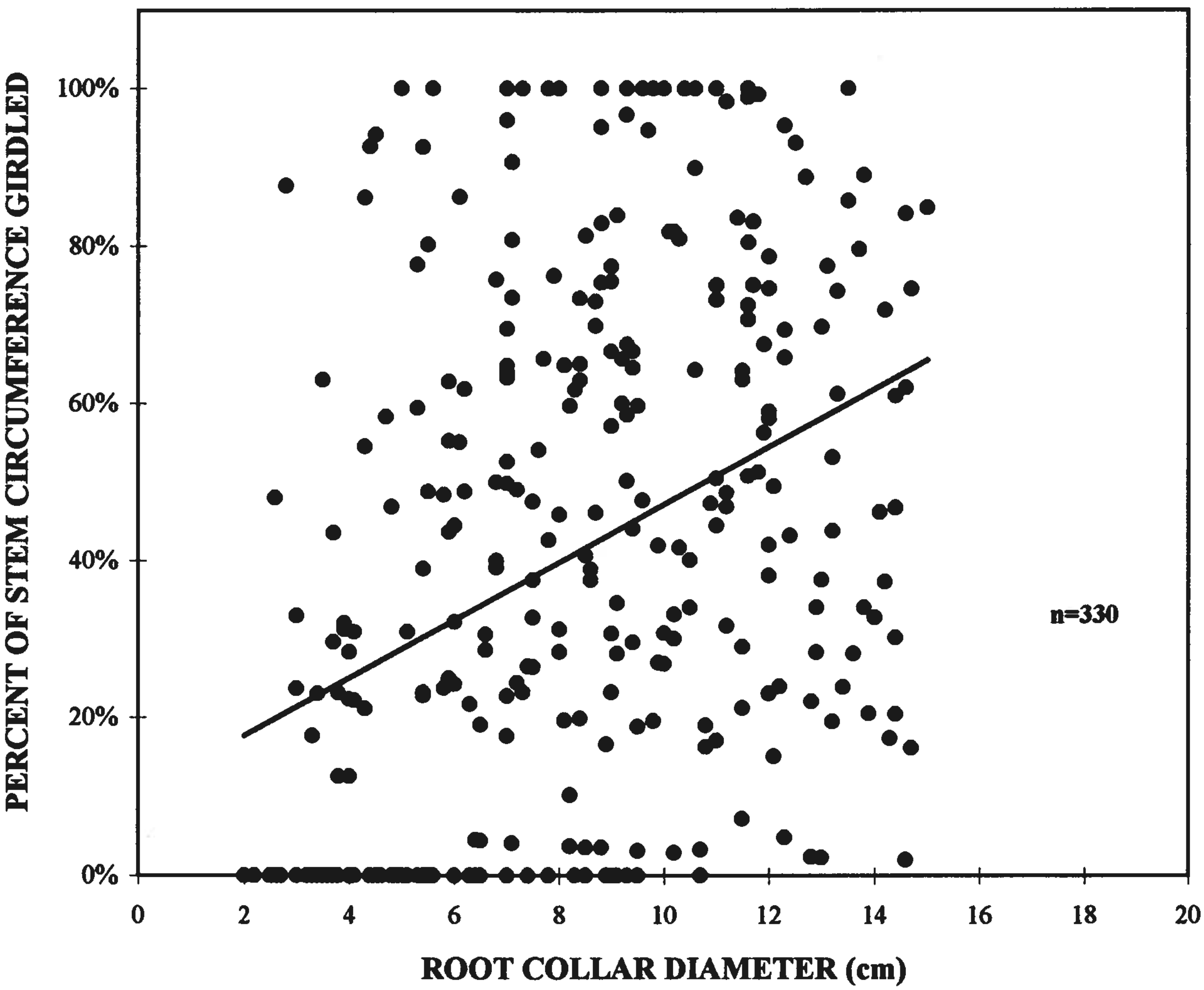

Figure 11. Percentage of sampled Lodgepole pine with *Hylobius warreni* damage in relation to root collar diameter at Date Creek in the Kispiox Forest District, Summer 1990. (% of stem girdled =11.00 + 3.36 x RCD, $R^2 = 0.14$, SE = 30.41, $p < 0.05$).

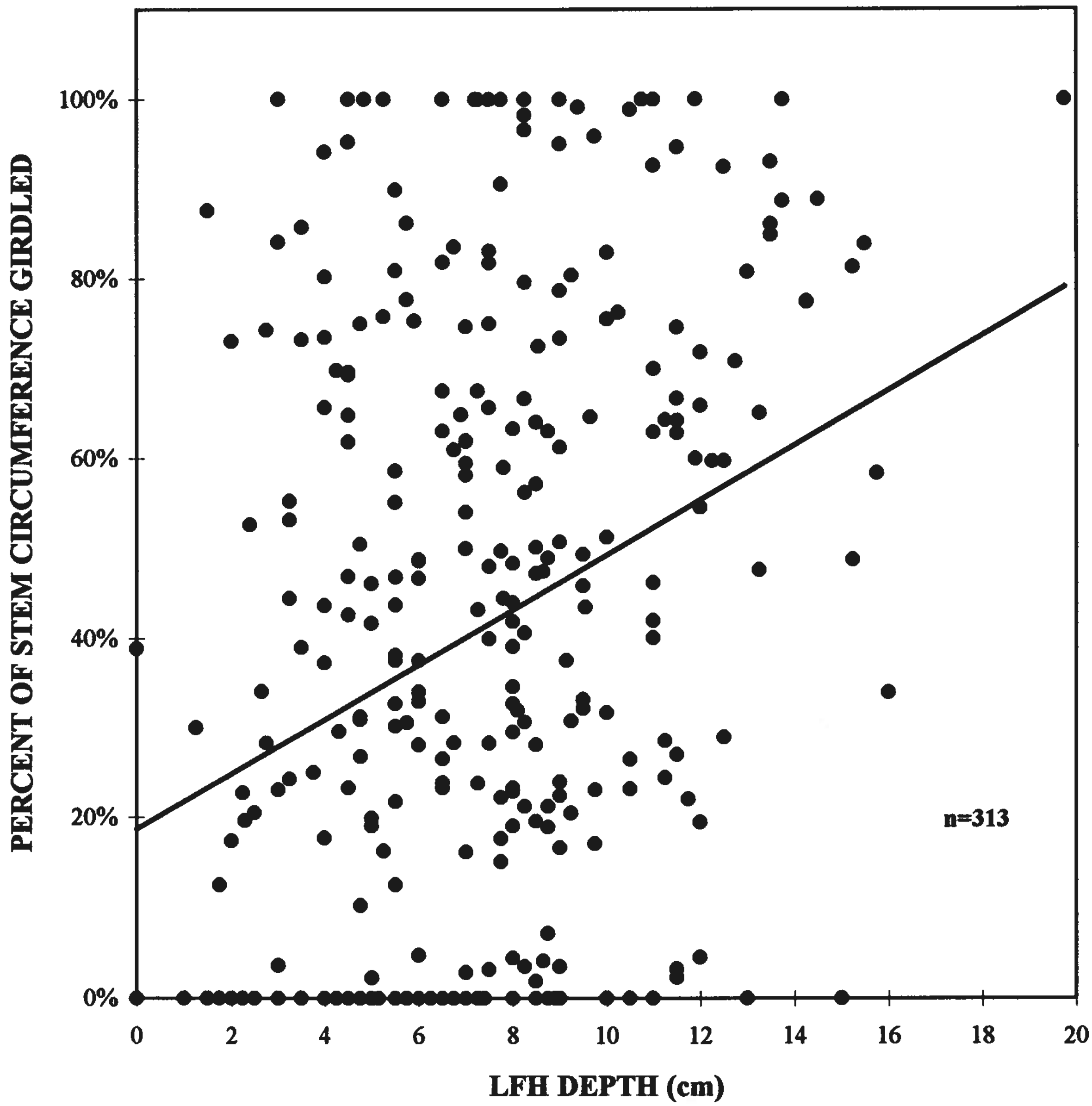

Figure 12. Percentage of sampled Lodgepole pine with *Hylobius warreni* damage in relation to average organic matter layer depth at Date Creek in the Kispiox Forest District, Summer 1990. (% of stem girdled = 18.67 + 3.06 x AVG LFH depth, $R^2 = 0.10$, SE = 31.06, $p < 0.05$)

3.2.1.2 Mosquito Flats

Eighty-four percent of all sampled trees had evidence of weevil feeding (Table 4). Eighty-eight percent of all sampled pine had evidence of weevil damage, while 11% of sampled spruce had been damaged by root collar weevil feeding. Sixty percent of the dead pine were killed by weevil girdling and 40% were killed by stem infections of western gall rust (*Endocronartium harknessii* (J.P.Moore) Y.Hirat). However, total mortality within the plot was only 2% of sampled stems (Table 4).

The average diameter of attacked lodgepole pine was 14.1 cm (Table 5). The average number of weevil larvae per tree was 1.4. The number of weevils per hectare, based on the average number of weevils per tree and the estimated stems per hectare, was 1100. The percentage of trees attacked within a diameter class increased with increasing diameter class (Figure 13). There was a significant regressions between percentage of the root collar girdled and both root collar diameter (Figure 14) and LFH depth (Figure 15).

The Mosquito Flats plantation had a small outbreak of a sawfly (*Neodiprion nanulus contortae* Ross) (Rod Garbutt Pers. Comm.)[4] during the summer of 1990; however, damage was minor.

[4] Forest Insect and Disease Ranger, Prince Rupert Forest Region

Table 4. Number and percentage of sample trees attacked by *Hylobius warreni*, by host species, at Mosquito Flats in the Kispiox Forest District, Summer 1990.

	Lodgepole pine			Spruce	
	Attacked	**Unattacked**	**Dead**	**Attacked**	**Unattacked**
Total Trees	235	34	5	1	9
Stems per hectare	783	113	17	3	30
% of Species Total	86	12	2	11	89

Table 5. Population estimates of *Hylobius warreni* and characteristics of attacked lodgepole pine trees at Mosquito Flats in the Kispiox Forest District, Summer 1990.

	RCD[a] (cm)	% GIRDLE[b]	Weevil Numbers per Tree				LFH[f] (cm)
			1ST YEAR[c]	2ND YEAR[d]	3RD YEAR[e]	TOTAL	
AVERAGE	14.1	60	0.2	0.5	0.7	1.4	7
S.D.	4.2	30	0.5	1.0	1.1	0.9	4

a. Root Collar Diameter

b. % of root collar circumference girdled

c. Larvae hatched from the current years eggs (1990)

d. Larvae hatched from 1989 eggs.

e. Larvae and pupae from 1988 eggs

f. Average depth of organic layer above mineral soil.

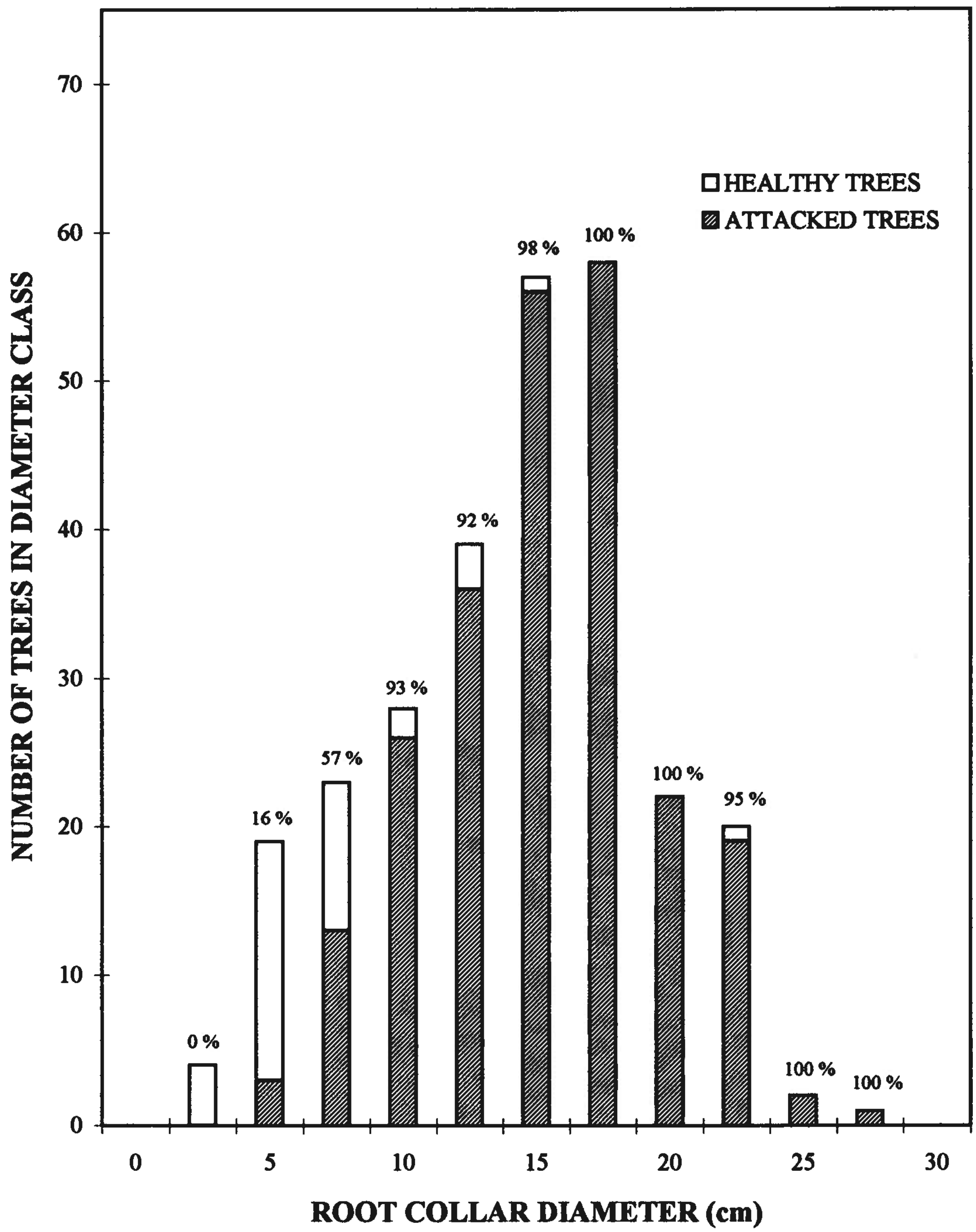

Figure 13. Diameter distribution of sampled Lodgepole pine trees and proportion attacked by *Hylobius warreni* at Mosquito Flats in the Kispiox Forest District, Summer 1990.

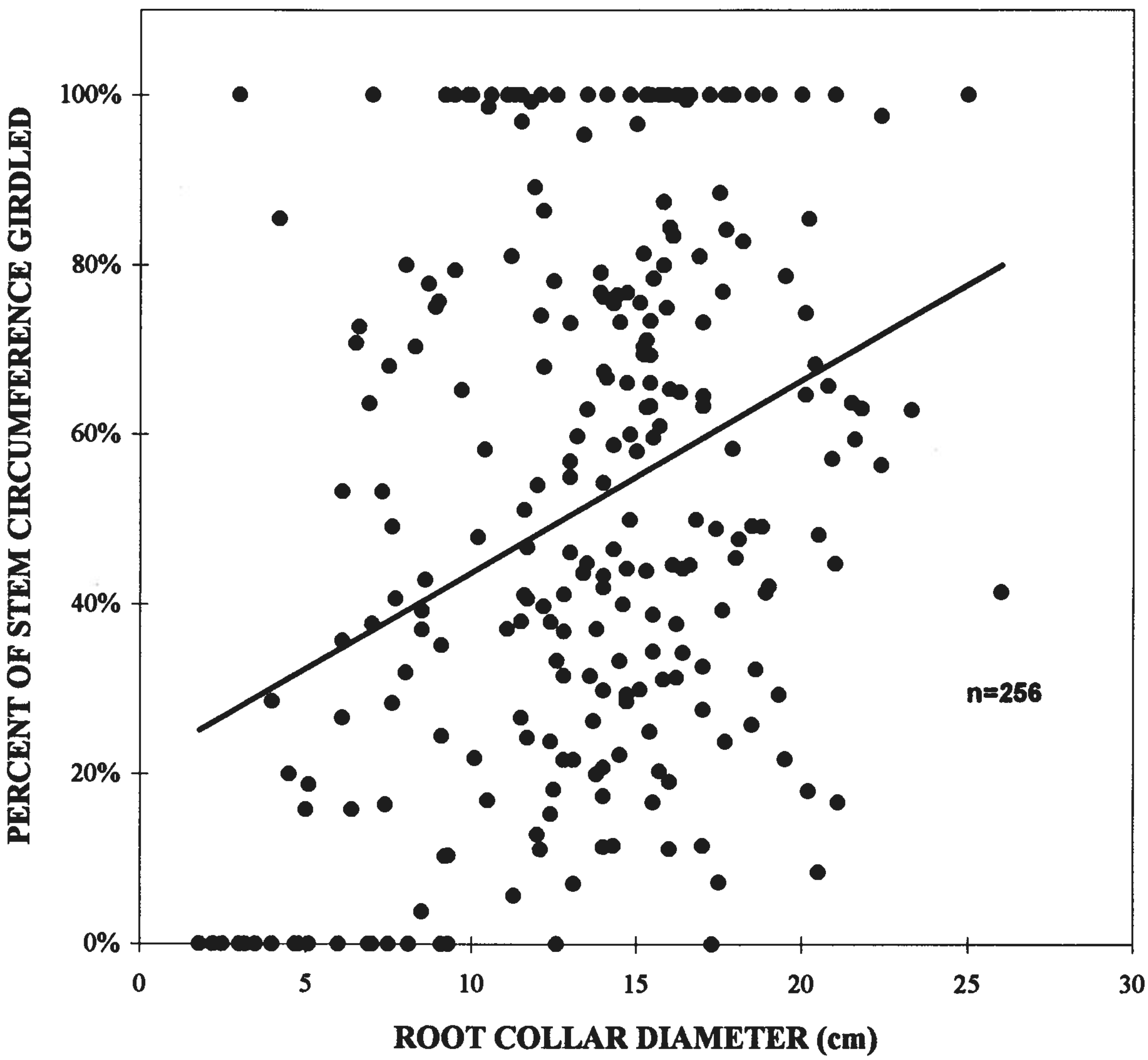

Figure 14. Percentage of sampled Lodgepole pine with *Hylobius warreni* damage in relation to root collar diameter at Mosquito Flats in the Kispiox Forest District, Summer 1990. (% of stem girdled = 21.10 + 2.27 x RCD, $R^2 = 0.12$, SE =30.11, $p < 0.05$)

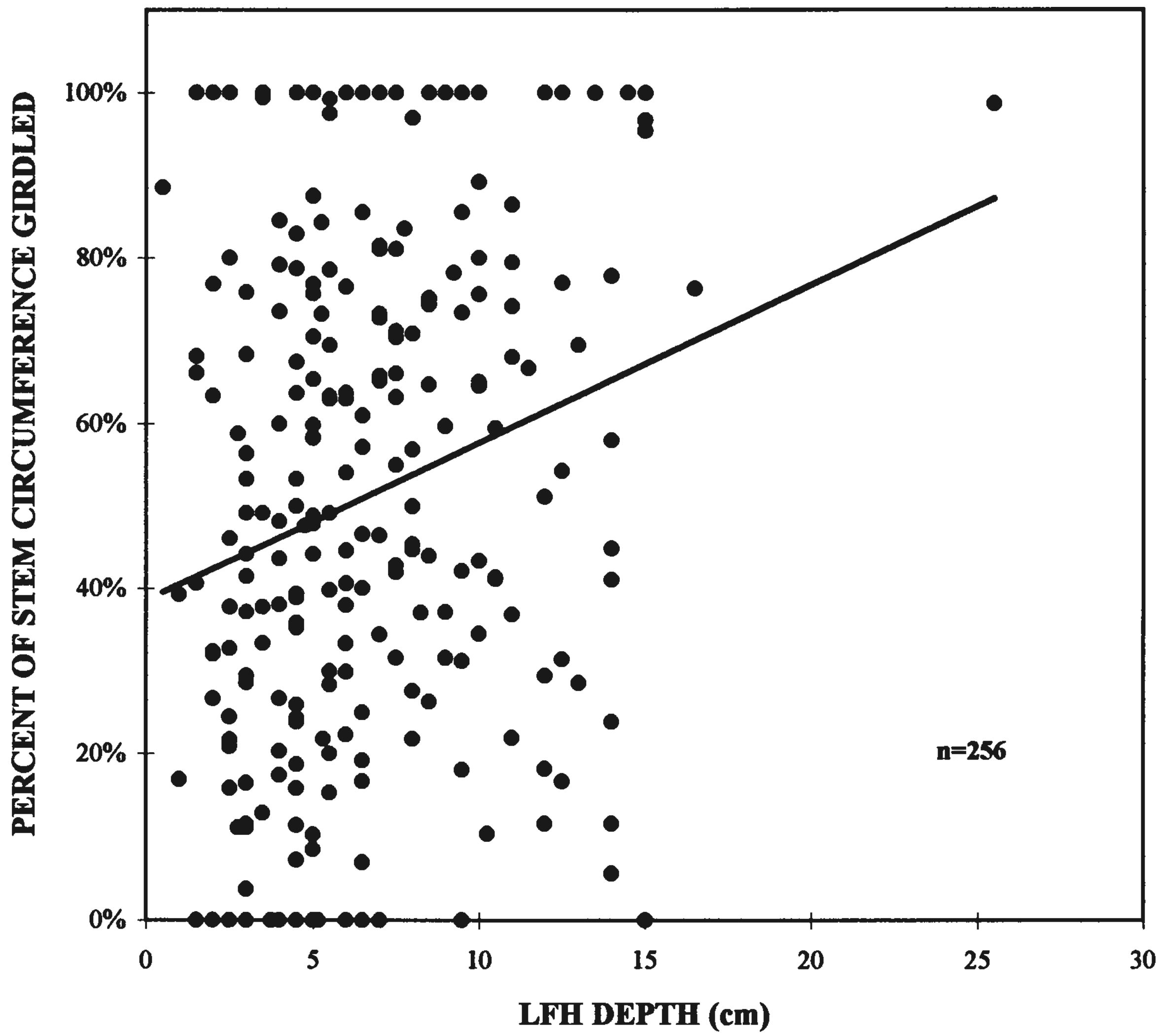

Figure 15. Percentage of sampled Lodgepole pine with *Hylobius warreni* damage in relation to average organic matter layer depth at Mosquito Flats in the Kispiox Forest District, Summer 1990. (% of stem girdled = 38.60 + 1.91 x LFH depth, $R^2 = 0.05$, SE = 31.23, $p < 0.05$).

3.2.1.3 Shandilla

Ninety-two percent of all sampled trees had evidence of weevil feeding (Table 6). Ninety-one percent of all sampled pine had evidence of weevil feeding, while 25 % of sampled spruce were attacked. Weevil caused mortality was 0.6 %.

The average diameter of attacked pine trees was 13.8 cm (Table 7). The average number of weevil larvae per tree was 2.6. The number of weevils per hectare, based on the average number of weevils per tree and the estimated stems per hectare, was 3680. The percentage of trees attacked within a girdling class increased with increasing diameter class (Figure 16). There was a significant regression between the percentage of the stem girdled and both root collar diameter (Figure 17) and LFH layer depth (Figure 18).

3.2.2 Pattern of Attack

Destructively sampled trees had been attacked within the last 5-6 years (Tables 8-10). The earliest attacks on trees in Date Creek and Mosquito Flats occurred in 1984, while the earliest attacks in Shandilla occurred in 1987. The majority of attacked trees had both old and new attacks.

The time of weevil attack was uniform throughout the plots (Tables 8-10). Trees at the periphery of the plot were attacked during the same years as those within the interior of the plot.

The proportion of trees attacked within a basal area class increased with increasing basal area for all three surveyed plantations (Figure 19).

3.2.3 Stem Analysis

3.2.3.1 Date Creek

Root collar diameter (RCD) and diameter at breast height (DBH) were significantly greater in the attacked girdling classes than in the unattacked girdling class (Table 11). Average tree height in all three damaged girdling classes was greater than the average total height of unattacked trees (Figure 20). Annual height increment in the 1-50 % girdling class during 1989

Table 6. Number and percentage of sample trees attacked by *Hylobius warreni*, by host species, at Shandilla in the Kispiox Forest District, Summer 1990.

	Lodgepole pine			Spruce	
	Attacked	**Unattacked**	**Dead**	**Attacked**	**Unattacked**
Total Trees	424	35	3	1	3
Stems per hectare	1413	117	10	3	10
% of Species Total	92	7.5	0.5	33	67

Table 7. Population estimates of *Hylobius warreni* and characteristics of attacked lodgepole pine trees at Shandilla in the Kispiox Forest District, Summer 1990.

			Weevil Numbers per Tree				
	RCD[a] (cm)	% GIRDLE[b]	1ST YEAR[c]	2ND YEAR[d]	3RD YEAR[e]	TOTAL	LFH[f] (cm)
AVERAGE	13.8	60	0.2	0.6	1.8	2.6	9
S.D.	3.2	30	0.5	0.8	2.7	1.3	4

a. Root Collar Diameter

b. % of root collar circumference girdled

c. Larvae hatched from the current years eggs (1990)

d. Larvae hatched from 1989 eggs.

e. Larvae and pupae from 1988 eggs

f. Average depth of organic layer above mineral soil.

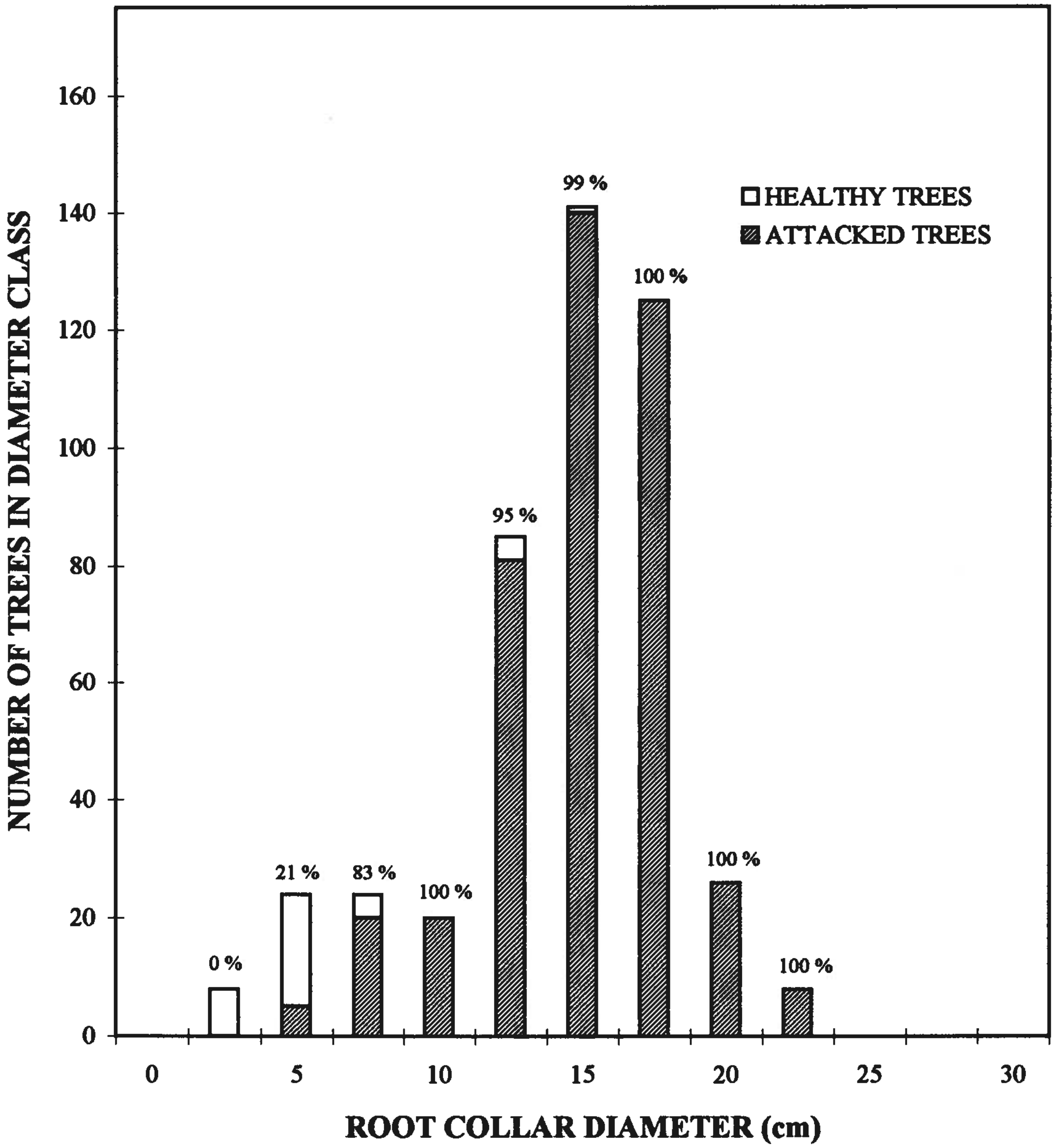

Figure 16. Diameter distribution of sampled Lodgepole pine trees and proportion attacked by *Hylobius warreni* at Shandilla in the Kispiox Forest District, Summer 1990.

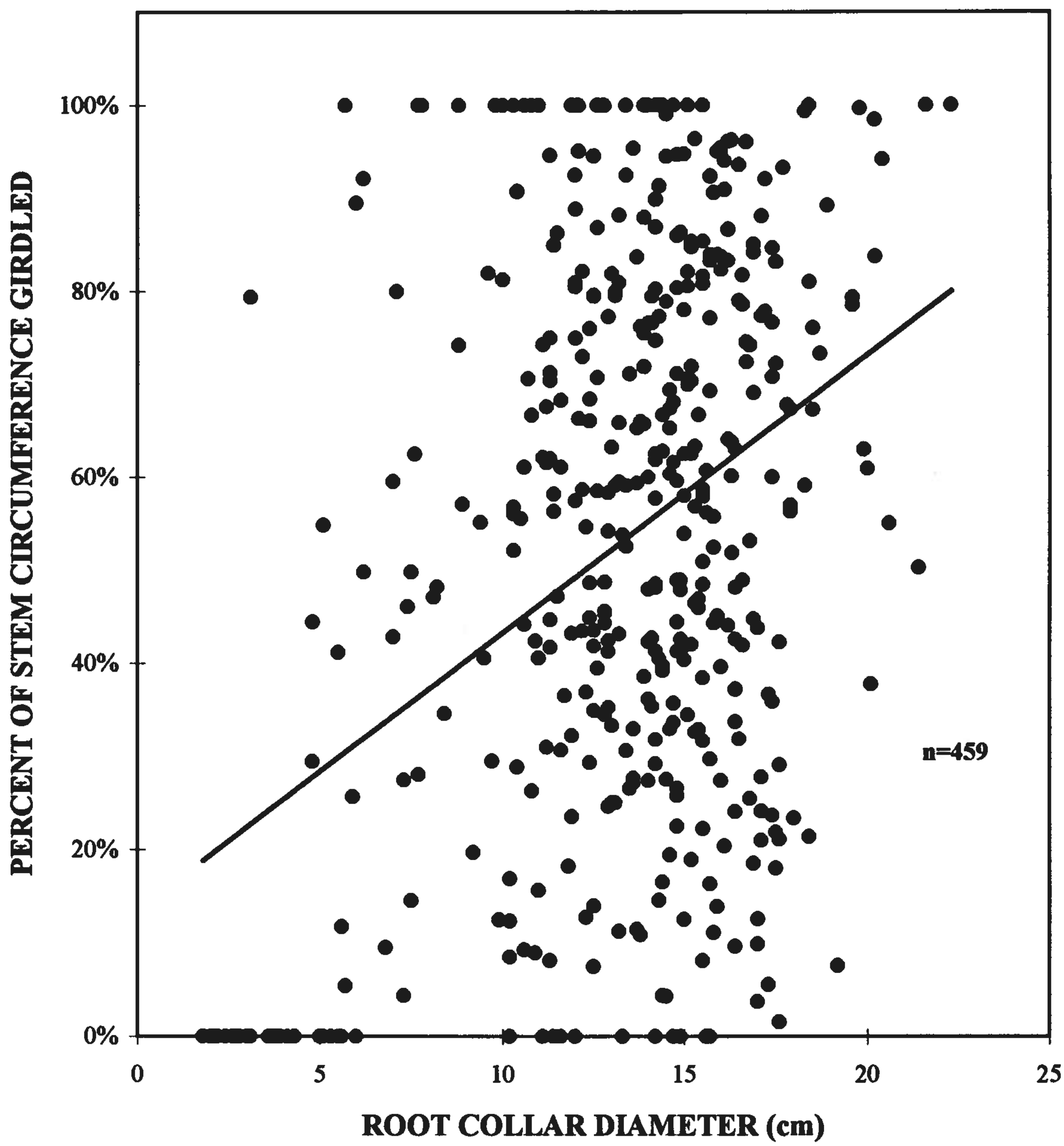

Figure 17. Percentage of sampled Lodgepole pine with *Hylobius warreni* damage in relation to root collar diameter at Shandilla in the Kispiox Forest District, Summer 1990. (% of stem girdled = 13.44 + 2.99 x RCD, $R^2 = 0.15$, SE = 28.76, $p < 0.05$).

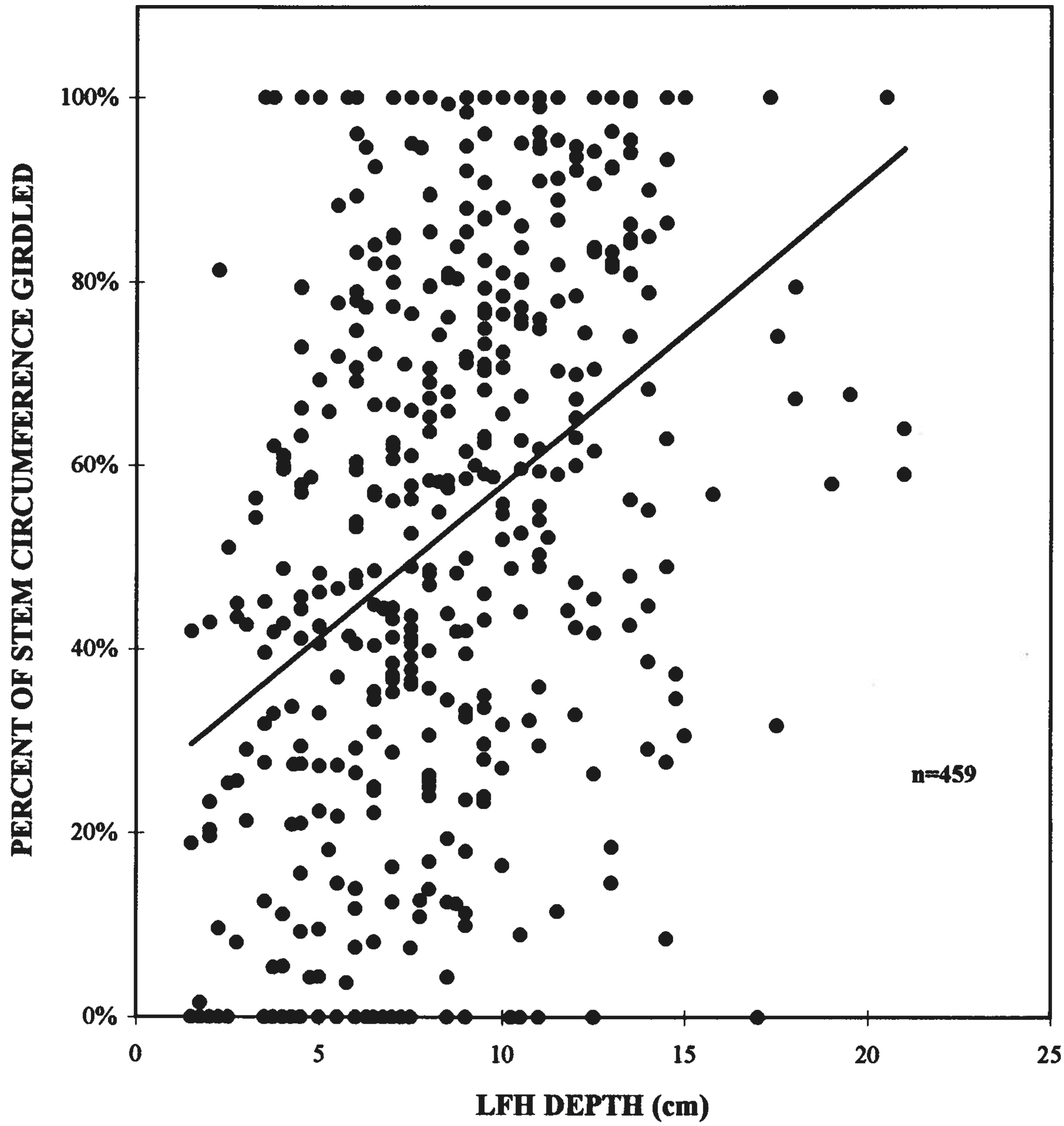

Figure 18. Percentage of sampled Lodgepole pine with *Hylobius warreni* damage in relation to average organic matter layer depth at Shandilla in the Kispiox Forest District, Summer 1990. (% of stem girdled = 24.71 + 3.32 x LFH, $R^2 = 0.15$, SE = 28.83, $p < 0.05$).

Table 8. Timing of attack of *Hylobius warreni* on sample trees in a 13 year old lodgepole pine plantation at Date Creek in the Kispiox Forest District, Summer 1990.

Tree #	% Girdled[a]	RCD[b](cm)	Year(s) of Attack
44	0	11.5	Nil
206	0	10.2	Nil
239	0	9.3	Nil
318	0	9.5	Nil
341	0	10.3	Nil
376	16	18.0	1987-1989
96	20	16.3	1986-1989
287	20	15.1	1987-1989
345	30	15.5	1987-1989
70	47	13.2	1985-1989
212	53	14.4	1987-1989
216	53	14.2	1987-1989
371	61	16.0	1985-1989
207	62	16.5	1984-1989
139	66	13.2	1985-1989
98	72	15.2	1985-1989
178	75	18.0	1986-1989
389	84	16.3	1984-1989
221	89	15.0	1984-1989
277	99	14.0	1987-1989

a. % of root collar circumference girdled.

b. Root Collar Diameter

Table 9. Timing of attack of *Hylobius warreni* on sample trees in a 17 year old lodgepole pine plantation at Mosquito Flats in the Kispiox Forest District, Summer 1990.

Tree #	% Girdled[a]	RCD[b](cm)	Year(s) of Attack
83	0	12.6	Nil
107	0	10.9	Nil
160	0	10.6	Nil
179	0	20.4	Nil
20	8	20.5	1987-1988
198	17	21.1	1987-1989
273	18	20.2	1987-1989
39	22	19.5	1987-1989
182	48	20.6	1988-1989
254	57	20.9	1987-1989
48	62	23.3	1984-1989
281	63	21.5	1988-1989
284	65	21.8	1987-1989
44	69	21.6	1987-1989
32	82	18.2	1987-1989
127	84	17.7	1986-1989
277	85	21.2	1985-1989
280	85	20.2	1985-1989
46	98	22.4	1987-1989

a. % of root collar circumference girdled.

b. Root Collar Diameter.

Table 10. Timing of attack of *Hylobius warreni* on sampled trees in a 17 year old lodgepole pine plantation at Shandilla in the Kispiox Forest District, Summer 1990.

Tree #	% Girdled[a]	RCD[b](cm)	Year(s) of Attack
510	0	10.2	Nil
531	0	11.6	Nil
547	0	14.2	Nil
626	0	11.1	Nil
966	0	12.0	Nil
612	8	19.2	1989
591	21	17.6	Pre-1987
880	21	18.4	1987-1989
549	38	14.9	1987-1989
668	38	20.1	1987-1989
876	51	21.4	1988-1989
921	55	20.6	1987-1989
877	63	19.9	1987-1989
743	79	19.6	1987-1989
862	79	19.6	1987-1989
871	84	20.2	1987-1989
771	89	18.9	1987-1989
673	94	20.4	1986-1989
889	98	20.2	1987-1989
727	99	19.8	1987-1989

a. % of root collar circumference girdled.

b. Root Collar Diameter.

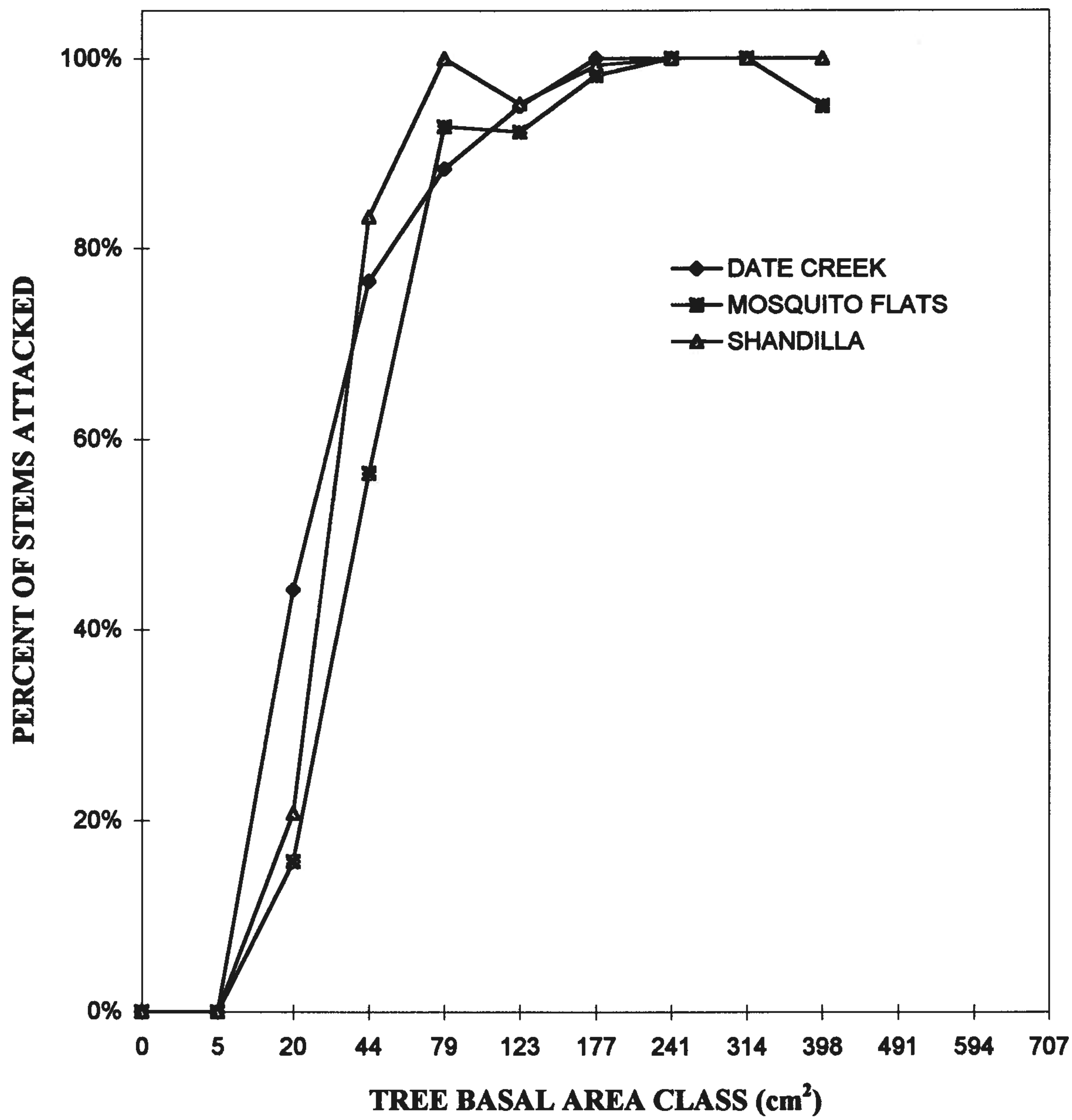

Figure 19. Percentage of sample lodgepole pine with *Hylobius warreni* damage in relation to basal area class for three plantations in the Kispiox Forest District, Summer 1990.

Table 11. Stem analysis of lodgepole pine trees attacked by *Hylobius warreni* at Date Creek in the Kispiox Forest District, Summer 1990.

Girdle[1] Class	RCD[2] (cm)	DBH[3] (cm)	Average Internode Length									
			1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
0%	10.2a[4]	7.7a	27.4a	37.4a	47.2a	54.2a	60.0a	49.8a	48.8a	47.2a	44.0a	55.6ab
1-50%	16.2b	11.3b	47.0a	45.2a	59.8a	54.2a	59.6a	62.2a	51.8a	49.8a	42.4a	72.0b
51-70%	14.9b	10.7b	49.6a	48.0a	62.8a	61.4a	60.4a	57.6a	59.0a	57.8a	49.2a	49.2a
71-99%	15.7b	11.2b	47.2a	54.6a	44.2a	46.8a	66.6a	69.2a	59.2a	45.2a	45.6a	42.6a

1. % of root collar circumference girdled

2. Root Collar Diameter

3. Diameter at Breast Height

4. Means followed by the same letter not significantly different (SNK; $P<0.05$)

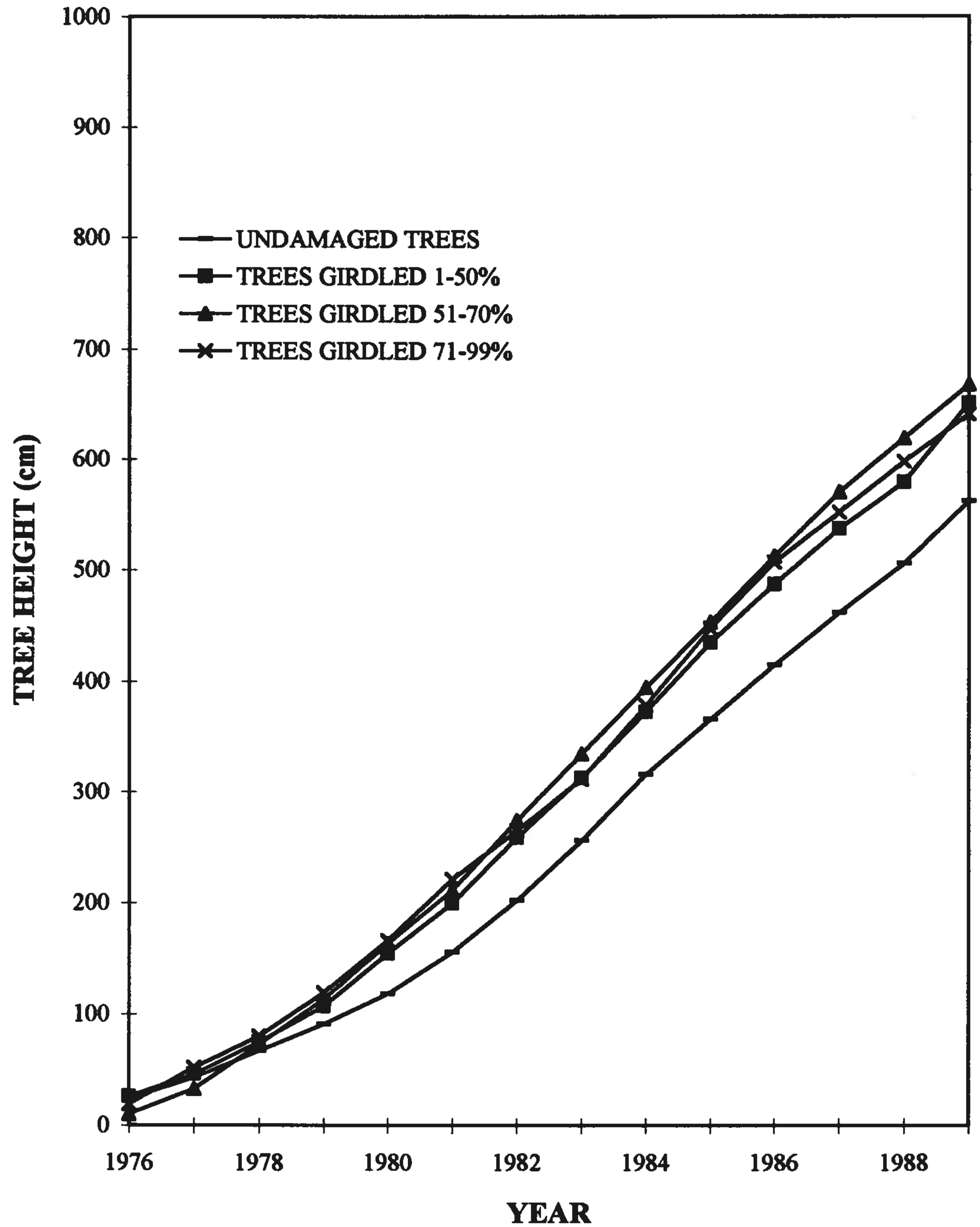

Figure 19. Cumulative average tree height of lodgepole pine, in four *Hylobius warreni* girdling classes, at Date Creek in the Kispiox Forest District, Summer 1990.

was significantly greater than the height increment in all other girdling classes (Table 11). However, there were no significant differences in annual height increments between the girdling classes in any other year.

3.2.3.2 Mosquito Flats

Root collar diameters were significantly greater in all attacked girdling classes than in the unattacked girdling class (Table 12). The 1-50 % and 51-80 % girdling classes had significantly larger DBH's than did the unattacked girdling class. Average tree height was greater in all three damaged classes than in the unattacked girdling class (Figure 21). Height increment was significantly larger for attacked trees in all girdling classes in 1979 when compared with unattacked trees (Table 12). There were also significant differences between unattacked trees and trees in both the 51-80 % and 81-99 % girdling classes in 1980. However, unattacked trees had shorter height increments in both years.

3.2.3.3 Shandilla

Root collar diameters were significantly larger in all attacked girdling classes when compared with the unattacked class (Table 13). The 1-50 % girdling class had significantly smaller RCD's than did the 51-80 % and 81-99 % girdling classes. Unattacked trees had significantly smaller DBH's than did attacked trees, while trees in the 1-50 % girdling class had significantly smaller DBH's than those in the 51-80 % girdling class. The average heights of attacked trees in all three girdling classes were taller than trees in the 0% girdling class (Figure 22). Unattacked trees had significantly shorter height increments than those in the 51-80 % girdling class during 1979 and 1980 (Table 13). Unattacked trees had significantly shorter increments than trees in all other girdling classes in 1984. Height increments were significantly greater in the 1-50 % class than in the 51-80 % class during 1989.

Table 12. Stem analysis of lodgepole pine trees attacked by *Hylobius warreni* at Mosquito Flats in the Kispiox Forest District, Summer 1990.

			Average Internode Length (cm)										
Girdle[1] Class	RCD[2] (cm)	DBH[3] (cm)	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
0%	13.6a[4]	10.2a	18.5a	27.8a	29.8a	61.0a	53.8a	61.0a	61.3a	50.8a	48.0a	44.3a	55.5a
1-50%	20.4b	13.5b	50.8b	45.8ab	63.0a	54.6a	58.2a	61.2a	59.4a	65.4a	52.0a	52.4a	52.2a
51-80%	21.8b	14.2b	61.8b	52.8b	50.8a	57.8a	51.8a	47.2a	39.2a	45.0a	45.8a	51.8a	39.8a
81-99%	19.9b	12.5ab	57.2b	55.6b	46.4a	59.8a	51.6a	70.4a	38.8a	51.8a	47.8a	43.8a	39.8a

1. % of root collar circumference girdled

2. Root Collar Diameter

3. Diameter at Breast Height

4. Means followed by the same letter not significantly different (SNK; $P<0.05$)

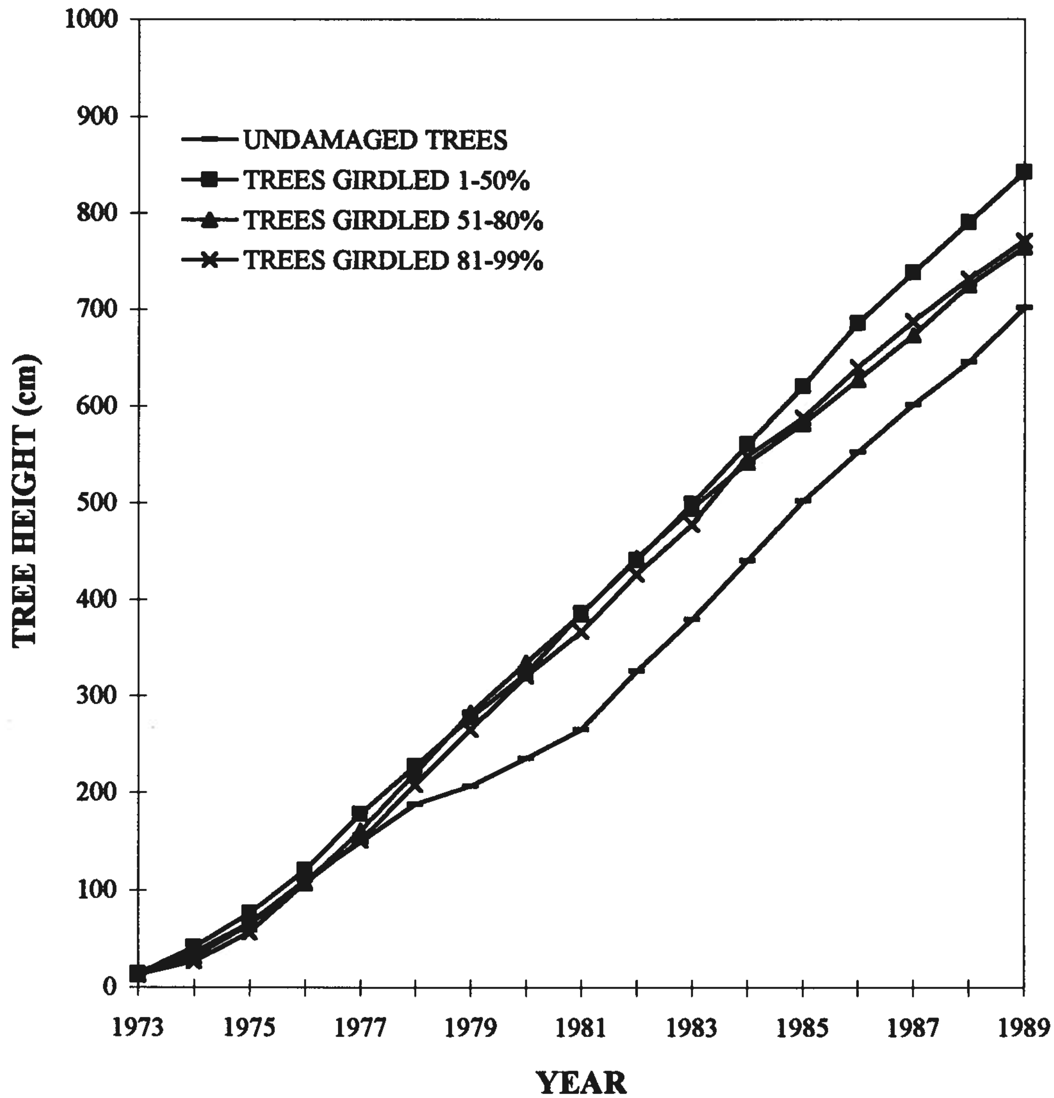

Figure 21. Cumulative average tree height of lodgepole pine, in four *Hylobius warreni* girdling classes, at Mosquito Flats in the Kispiox Forest District, Summer 1990.

Table 13. Stem analysis of lodgepole pine trees attacked by *Hylobius warreni* at Shandilla in the Kispiox Forest District, Summer 1990.

Girdle[1] Class	RCD[2] (cm)	DBH[3] (cm)	Average Internode Length (cm)										
			1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
0%	11.8a[4]	8.7a	37.0a	40.6a	41.4a	49.8a	51.0a	56.2a	52.4a	49.0a	58.6a	44.3a	52.0a
1-50%	18.0b	12.6b	44.8ab	51.0ab	48.6a	53.6a	68.8a	71.4b	67.8a	52.6a	49.2a	56.6a	60.0b
51-80%	20.2c	15.1c	55.4b	61.4b	64.8a	71.0b	70.6a	74.8b	64.0a	56.4a	55.8a	55.4a	38.4a
81-99%	19.9c	13.5bc	46.0ab	56.4ab	62.8a	67.4b	66.0a	76.8b	56.8a	62.4a	57.0a	50.2a	52.0ab

1. % of root collar circumference girdled

2. Root Collar Diameter

3. Diameter at Breast Height

4. Means followed by the same letter not significantly different (SNK; $P<0.05$)

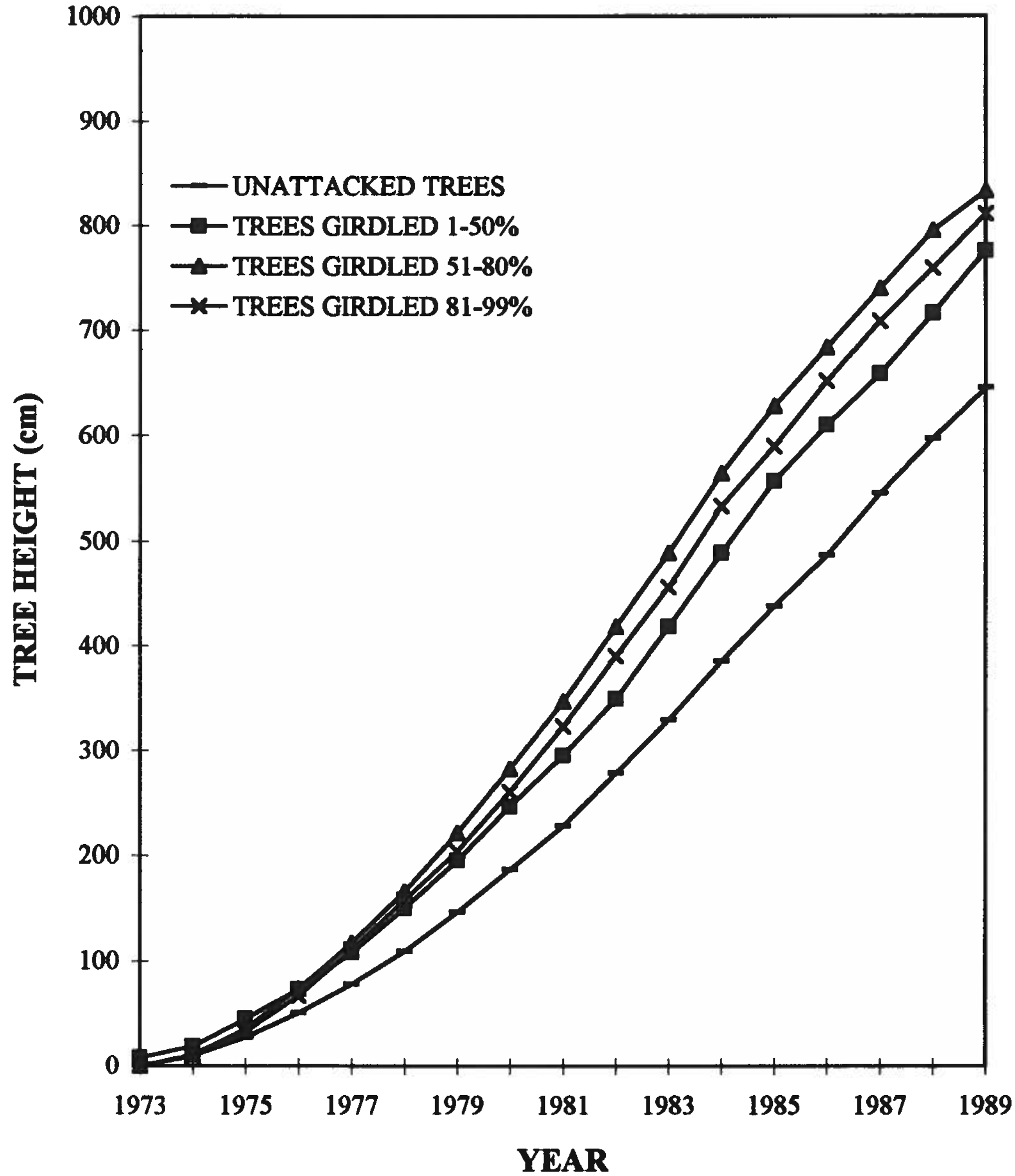

Figure 22. Cumulative average tree height of lodgepole pine, in four *Hylobius warreni* girdling classes, at Shandilla in the Kispiox Forest District, Summer 1990.

4.0 DISCUSSION

4.1 Distribution and Abundance of Warren's Collar Weevil

The 3.99 m radius circular plot was chosen for the district wide survey for a number of reasons. First, circular plots were easier to establish than were strip plots. One person could put in a circular plot, whereas two people would be needed to establish a strip plot, thus requiring twice the time. Ease of establishment was important for the following reasons. In order to fulfill the goal of surveying 30 plantations in a 16 week period, it was necessary to optimize labour resources. The circular plot enabled almost twice the area to be surveyed with the same size crew. Also, if the survey was to be cost effective in the long run (*i.e.* could be integrated into the present Ministry of Forests silviculture surveys format), it was advantageous to have a method that could be implemented by a crew of one. This would keep survey costs at a reasonable level.

Second, circular plots are commonly used in other silviculture assessments such as regeneration and free-growing surveys. The data required to assess Warren's collar weevil abundance could be easily collected at the same time as a free-growing survey. The survey method was quite effective in assessing weevil damage. In only one case, the Seven-Sisters plantation in the SW region of the district, did the plots fail to contain trees with weevil larval damage when there was evidence of it within the plantation.

Third, the time required to establish a circular plot was generally less than the time needed to put in strip plots (this was dependent on tree density). For strip plots, data gathering was a continuous process, whereas in circular plots, more time was spent travelling between plots.

Fourth, circular plots could be distributed more evenly throughout a plantation than strip plots. Because of the continuous nature of strip plots, the minimum coverage within a given hectare was 2% of the area. To achieve the desired sampling intensity of 1% of the area for the study, it would not be possible to survey every hectare within a plantation using the strip plot method. The circular plot ensured that there were at least two plots per hectare (or 1 plot/ha for a 0.5 % intensity survey). Weevil populations are contagious in distribution (Cerezke 1969), thus the circular plot survey may be more useful for detecting weevil attacked trees, since it covers more ground than does the strip survey.

The lesser perimeter of the circular plot (25 m vs 54 m for strip plots) resulted in fewer judgement calls of whether a tree was in or out of the plot. This minimized potential error associated with judgement calls. It also reduced the time spent determining if a tree was within a plot or outside of it.

The surveyed plantations were well distributed within the district, and provided a good overview of the distribution of Warren's collar weevil. The wide range of ages of plantations surveyed provided some insight into the expected levels of Warren's collar weevil in the development of plantations to the free-growing stage. For example, based on this survey, a 6 year old stand with 5 % weevil incidence might be expected to have a 45 % weevil incidence by age 15 years. Plantations within a given drainage were of similar ages. For example, plantations in the Upper Kispiox River were relatively young (5-7 years), while plantations in the Suskwa River drainage were among the oldest in the district (10-16 years).

The average percentage of sampled lodgepole pine with larval damage was found to be greater in the Kispiox Forest District than values reported in Alberta. Near Robb, Alberta, Cerezke (1969) reported attack rates of between 2.8% - 13.7% for 2.8 m -3.2 m tall lodgepole pine.

The average number of weevils per tree was greater than those previously reported for similar stands. Cerezke (1970c) found between 0.03 and 0.13 weevils per tree in 15 and 20 year old stands in Alberta. This was considerably less than the 0.33 weevils per tree found in this study. The higher weevils per tree found in this study may have been a result of differences in stand density and not population levels. In Alberta, Cerezke's studies were done in natural lodgepole pine stands where tree densities were quite high (> 2500 sph). This study concentrated on pine plantations in which planting densities were generally in the range of 1100 -1300 sph. Thus, in plantations, weevil numbers per tree may be greater than would be found in naturally regenerated pine plantations.

The average mortality rates attributed to Warren's collar weevil larval damage were within levels reported by Cerezke (1969). Some young plantations within the district had high levels of larval caused mortality. In particular, two 5 year old plantations in the Salmon River area had high mortality levels (6% and 8.8%). These plantations were established on a flat bench adjacent to the Salmon River. The high mortality levels may have been a result of the harvesting pattern in this area. The original stands were dominated by mature lodgepole pine which was attacked by mountain pine beetle (*Dendroctonus ponderosae* Hopkins). These stands were salvage harvested and planted to lodgepole pine the following year. Residual mature lodgepole pine within the area exhibited evidence of root collar weevil. The weevil populations in the clearcut areas immediately following harvesting (*i.e.*, the first two years post-harvest) would have increased due to decreased development times in the cut stumps (Cerezke 1973b). These weevils would have dispersed from the clearcut areas to find any available suitable host. In this case, they attacked residual pine adjacent to clearcut areas. These adjacent areas were subsequently logged (*i.e.* 3 and 4 years following the harvest of the surveyed plantations), further decreasing the pine component in the area. Weevil populations in these blocks following harvest would also have increased; however, the residual populations would have had few places to inhabit because of the continued removal of the pine type. Because of a lack of larger, more suitable pine trees in the area, adult weevils would have then invaded the original pine plantations, which were then 4 or 5 years old. The high levels of mortality would have been a result of both the high weevil populations and the small size of the host.

The free-growing status of surveyed plantations was being affected by root collar weevil. By definition, a free-growing, or acceptable well-spaced stem, must be free of insect damage. The survey indicated that potential well-spaced stems were being attacked by root weevil. The effect that this insect will have over the duration of the stand is not known. Mortality rarely occurs in attacked trees older than 30 years (Cerezke 1969). Perhaps free-growing assessments should be delayed in plantations known to support weevil infestations to ensure that the weevil is not preventing free-growing standards from being achieved. Another alternative would be to schedule reconnaissance surveys in plantations between 20 and 30 years old to assess the health and stocking of stands which have been declared free-growing.

In the Kispiox Forest District, it can be expected that the percentage of trees attacked by root collar weevil will increase as stand age and average tree height within plantations increase. This will occur for two reasons: increasing suitability of the host trees, and relatively constant stand densities. The population of weevils within naturally regenerated stands is constant over the life of that stand (Cerezke 1970a). As the stand ages, natural thinning processes reduce tree densities. Those trees that remain will be the larger, more dominant trees which are better able to compete for light and available resources. It is this group of trees which is most susceptible to attack by Warren's collar weevil. In plantations, trees are planted at target harvest densities, so natural mortality is much lower than in natural stands. Therefore, the percentage of stems attacked in plantations will increase much more rapidly than in natural stands since the number of stems are already at culmination densities. In addition, diameter growth will be greater in plantations because resources are not being lost to trees that would be naturally thinned out. Thus planted trees may provide better weevil habitat at a younger age than naturally regenerated trees.

The probability of a tree being attacked was related to its basal area. The proportion of trees attacked within a basal area class increased with increasing basal area. This may be related to the nutritional quality of the host tree. The suitability of the phloem as a nutritional source for larvae may increase with increasing tree size. It has also been suggested (G. Weetman [5] pers. comm.) that the incidence of the weevil may be related to crown closure. The ability of a stand to support a weevil infestation may increase as it approaches 100% crown closure. The understorey shading associated with crown closure may be a critical factor in weevil survival.

There was no apparent relationship between the percentage of trees with Warren's collar weevil damage and the total number of stems/ha (Figure 5). Cerezke (1970c) reported evidence that excessively stocked stands provided poor weevil habitat. None of the plantations surveyed were excessively stocked with dominant/co-dominant pine, as is found in some natural stands. Therefore, I would not expect tree density to have a large effect on the percentage of trees attacked. Some surveyed plantations had higher tree densities (> 2500 sph). These were composed of two tree layers. Trees that had seeded in naturally since planting (layer 1 trees) were generally smaller trees and germinants. It was this layer that resulted in the high densities recorded. Planted trees (layer 2 trees) were larger and at lower densities (~ 1200 sph). These trees had the most influence on stand conditions, and they better reflect the conditions that may affect the susceptibility of that stand to support weevil populations.

[5] Professor, Faculty of Forestry, The University of British Columbia

The depth of the LFH layer did not appear to be important in determining if trees were attacked in either study year. Cerezke (1970c) found that the duff depth (LFH) gave an indication of the quality of habitat, with the thicker, moister duff depths being the most suitable for larval survival. The method used to measure LFH depths in the first year of the study did not measure duff depth directly at the tree base. It was thought that this may have been the reason why a good relationship was not found. During the second year of the study, measurements of the LFH were made directly at the tree base. Measuring the LFH depth in this manner did show a significant relationship between the percent of the stem circumference girdled and the LFH depth. Although significant the equations accounted for only a small portion of the variation in circumference girdled at all three study sites. A more important factor to consider when assessing weevil habitat may be the quality of the LFH layer. Cerezke (1969) found that there were similarities in the LFH layer at the base of attacked trees. He found that sites with a mixture of a moss and herb layer over the LFH layer were common in attacked trees. This was also the case in the Kispiox district. Those sites with a mixture of herbs and mosses and a moist LFH layer had higher attack incidences. The presence of slash and small logs at the base of trees was also common in attacked trees. Presumably, this woody debris provides moisture and protection for developing larvae.

Pine plantations on circum-mesic, well-drained sites will be susceptible to infestation by Warren's collar weevil. Generally, these are the more productive sites for growing lodgepole pine. Proposed openings on such sites should be examined carefully at the pre-harvest prescription phase to assess the probability that weevils will affect the next stand. Suitable prescriptions can then be developed to limit the impact of Warren's collar weevil over the next rotation. The presence of pine adjacent to a plantation is important in determining its susceptibility to root collar weevil infestation (Cerezke 1989). The adjacent pine serves as a reservoir for root collar weevil populations.

Surveyed plantations which were site prepared either with burning or with scarification did not have lower percentages of weevil attacked trees than those plantations with no site preparation. In fact, openings which had a site preparation treatment had higher percentages of weevil attacked trees than those that did not. Site preparation is thought to reduce weevil survival by reducing the LFH layer, which is important to adult weevil survival (Cerezke 1973b, 1989). The benefits of site preparation may be being masked by the age of the plantations surveyed and the harvest scheduling. The average age for broadcast burned blocks was 16 years, 8 years for spotburn blocks, 6 years for no treatment, and 5 years for scarified blocks. Perhaps enough time had elapsed to allow for sufficient build-up of organic material in the burned blocks to support weevil re-invasion. Of the scarified blocks, only two had high weevil incidence. These were found in the Salmon River area, discussed above. The change in forest structure as a result of mountain pine beetle salvage may be more responsible for the high weevil populations than the failure of scarification to reduce the LFH layer. Site preparation may be an effective tool in delaying the onset of infestations. This may include broadcast burning and scarification.

4.2 Height Growth and Dispersal Study

With the exception of the Shandilla plantation, weevil populations found in the three study areas were consistent with those previously reported (Cerezke 1970c). In Alberta, weevil numbers per hectare in 15-20 year old stands were in the range of 375 to 920. The populations at Date Creek and Mosquito Flats were 850 weevils/ha and 1100 weevils/ha, respectively. Populations at Shandilla were considerably higher, with almost 3700 weevils/ha. The reason for the high populations may have been related to the original stand composition and the surrounding forest cover. The original stand was composed of approximately 15 -20 % lodgepole pine. The leading species on the site were hemlock and spruce. The surrounding forest cover consisted of mixed species stands dominated by western hemlock. The pine component in the area was negligible. The existing stand was an island of pine within a hemlock dominated forest. After harvesting of the original block, weevils may have dispersed to surrounding residual pine, and maintained the population until the planted pine was of susceptible size. The population then increased as a result of an increase in their preferred host. Dispersal from the pine plantation would be limited by the lack of lodgepole pine at the plantation periphery. When searching for hosts, adult weevils would be more successful if they remained within the plantation. This likely contributed to very high population levels within the Shandilla plantation.

There was a significant relationship between the root collar diameter of attacked trees and the percentage of the stem circumference girdled in all three sampled plantations. Although the relationship was significant the equation accounted for only a small portion of the variability in the percent of the root collar circumference girdled. The percent of the stem girdled increased with increasing root collar diameter; however, the usefulness of this relationship is limited by the low R^2 value associated with it.

The destructively sampled trees in this study had been attacked within the previous 5-6 years. This would imply that weevil populations may have increased dramatically within the previous five years. For instance, 92% of all lodgepole pine at Shandilla had been attacked within the previous four years. Likewise, 81 % and 87 % of lodgepole pine trees at Date Creek and Mosquito Flats respectively, had been attacked within the previous six to seven years. These attack rates were much greater than those reported in Alberta. Cerezke (1969) estimated that 10 - 30 % of the trees in 16-25 year old natural pine stands had evidence of weevil attack. Also, attack levels of greater than 90 % of a stand did not occur until they were at least 60 years old. His studies were done in natural stands in which high initial tree densities occurred. These stands will gradually thin by natural mortality, thus the increase in the percentage of trees attacked with relation to stand age is partially an artifact of decreasing stand density. In north central British Columbia, however, where plantations are planted at or near target densities, there is relatively little change in tree density during the life of the stand. Additionally, there are relatively few trees for weevils to attack compared to natural pine stands of similar age.

The high incidence of root weevils within the Kispiox Forest District in general, may be a result of the conversion of natural mixed species stands to pine plantations. The short period over which the natural pine stands within the district were harvested could also have contributed to the current high population levels. Weevil populations were likely present as small endemic infestations in natural stands prior to these stands being converted to managed forests. Reliance on lodgepole pine for regenerating circum-mesic sites within the district has resulted in a large increase in available weevil habitat. Contributing to this increase was the removal of much of the mature pine during mountain pine beetle salvage operations. Removing the majority of pine in certain areas, the Salmon River area for example, forced the weevil to disperse into young pine plantations. Had remnant pine stands been harvested over a longer time period, the population pressure within young plantations may have been reduced.

The time of weevil attack found on destructively sampled trees was uniform throughout the plots. Trees within the interior of the plot were attacked during the same time period as those trees at the periphery of the plot located at the stand margin. Cerezke (1969) estimated that weevil dispersal rate from the stand margin into naturally regenerated stands would be 10-15 m per year. To support this, destructively sampled trees at the stand periphery should indicate younger ages of attack than those sampled toward the interior of the plantation. This was not the case for the Kispiox. Weevils may be capable of longer distance dispersal than previously thought. Another possibility is that weevils remain in the clearcut and do not disperse to surrounding mature trees. Weevil larvae may complete development in cut stumps and the resultant adults could survive for up to four years. During this time, the adults would feed on residual conifer species until trees reached a size suitable for females to oviposit. Since it requires two years for newly hatched larvae to complete development within the cut stumps (Cerezke 1973b), the time from development of an adult to the time of its death would be six years after harvest. Thus planted trees within the cutblock would just be susceptible to attack prior to the fourth year of an adult weevil's lifespan. The pattern of weevil infestations was not clarified in this study.

Destructive sampling indicated that trees in the attacked girdling classes were significantly greater in size than were trees in the unattacked girdling class for all three study sites. This illustrated the weevil's preference for the larger dominant and co-dominant trees within a stand (Cerezke 1970a). Adult weevils oviposit at the root collars of the larger trees, presumably because they provide a better food source for the developing larvae. The mechanism by which adults select the larger trees within the stand is not known. Adults may choose trees based on visual cues such as stem thickness or tree height. This method of host selection has been demonstrated for the white pine weevil, *Pissodes strobi* Peck (VanderSar and Borden 1977). Alternatively, adults may choose trees based on olfactory cues. A related species, *Hylobius pales* (Herbst), a pest of plantation pines, has been shown to be attracted by a combination of turpentine and ethanol (Phillips *et. al*. 1988). Adults of Warren's collar weevil may respond to these compounds which are released by host trees. Weevil response may be dependent on the release rates of these compounds: *i.e.* larger trees emit larger quantities of such compounds than do smaller trees, thus attracting more weevils.

The results from the stem analysis indicated that there were no short-term impacts on lodgepole pine height growth as a result of weevil injury. Previous studies had found that girdling damage to the stem or root collar of lodgepole pine may result in growth losses. Cerezke (1970c) found reductions in height growth in pine damaged by root weevil larvae. Height growth was reduced by 11.5 % in the second year and 16.4 % in the third year following 50 % of the stem circumference girdled. In a partial girdling experiment, height growth declined gradually until 60 % of the stem was girdled. After 60 % of the stem was girdled, height growth declined rapidly (Cerezke 1974). Sullivan and Sullivan (1986) found that semi-girdling by the snowshoe hare (*Lepus americanus* Erxleben) significantly reduced height growth in lodgepole pine. Trees less than 6.0 cm at d.b.h. were most affected. Sullivan and Vyse (1987) reported conflicting results on the impact of semi-girdling damage by red squirrels (*Tamiasciurus hudsonicus* Erxleben) on height growth of lodgepole pine. Height growth was significantly affected in one stand, but it was not affected in another stand. However, they warned that growth impacts may not become evident until several years following the damage. Additionally, further feeding damage may adversely affect already damaged trees and thus increase the probability of future height growth reductions. This may reflect the situation found in this study. As trees are further damaged by subsequent weevil attacks, it is likely that growth reductions will occur. The average d.b.h. values for sample trees in this study were between 7.9 cm and 14.1 cm. These values are greater than the 6.0 cm values reported by Sullivan and Sullivan (1986). It is possible that the larger trees are more capable of repairing or overcoming weevil injury, although there was no evidence to indicate this in this study. Further, this study may not have found significant differences in height growth because of the obvious differences between girdled and control trees.

The Kispiox Forest District will likely continue to support higher weevil populations than those experienced in the past. The reliance on the use of lodgepole pine for reforesting natural mixed species stands will provide increasing habitat for Warren's collar weevil. The challenge is to keep populations of this insect at levels which are tolerable from a timber management perspective. Some management strategies which have been suggested include delaying planting until 2-3 years post-harvest, mixed species planting, planting at higher densities, and site preparation (Cerezke 1989). Management regimes which more closely mimic natural stands may reduce the impact of the weevil. These would include regeneration of mixed species historically found in the region.

5.0 CONCLUSIONS

1. Warren's collar weevil is found throughout the Kispiox Forest District.

2. Warren's collar weevil is not reducing plantations to below minimum required stocking levels. Weevil-caused mortality was generally quite low (< 5%) with a few exceptions. The free-growing status of lodgepole pine plantations is being affected by Warren's collar weevil. The presence of larvae and/or larval damage to well-spaced trees prevents them from being declared free-growing under current Ministry of Forests guidelines.

3. This study did not identify specific site factors which could be utilized to predict or identify areas which have the potential to support Warren's collar weevil infestations. A combination of general site conditions can identify potential problem areas. Pine plantations established on circum-mesic sites which previously had, or were adjacent to, timber types with a pine component appear to be most susceptible to colonization by Warren's collar weevil.

4. Destructively sampled lodgepole pine trees with Warren's collar weevil damage have been attacked over the previous 5 - 6 years. Trees have been attacked more than once during this time period.

5. Destructively sampled lodgepole pine trees with Warren's collar weevil damage were attacked during the same time period. There was no apparent progression of weevil infestation from the stand margin to the interior of the stand as reported in Alberta.

6. Warren's collar weevil has not yet had an effect on the height growth of attacked lodgepole pine trees. This finding may be confounded by the weevils apparent preference for larger diameter, dominant and co-dominant trees within a stand.

6.0 RECOMMENDATIONS

1. Warren's collar weevil should continue to be monitored in pine plantations within the Kispiox Forest District. The most suitable means of doing this is through the silviculture surveys system currently in use. The impact of the weevil on a site specific basis should be monitored either in conjunction with stocking surveys or through forest health surveys.

2. Warren's collar weevil should be monitored on a regional and district basis to better understand the impact of the weevil on a forest level basis.

3. The acceptability of well-spaced trees with Warren's collar weevil damage as free-growing stems should be resolved. The high incidence of damage within existing lodgepole pine plantations poses a potential liability to both the Crown and Licencees in the event that attacked stems cannot be declared free-growing.

4. The impact of Warren's collar weevil on the growth of attacked stems should be further studied. Longer term, more tightly controlled studies should be implemented to further determine the impact of larval feeding damage on the growth of attacked trees.

5. Operational trials that reduce populations of Warren's collar weevil in infested stands should be implemented in conjunction with harvesting activities. The best opportunity to limit damage by Warren's collar weevil is by limiting their re-invasion into plantations. The best means of achieving this should be examined.

6. Implement a detailed study of post-harvest survival of Warren's collar weevil in a stand, or stands, with a chronic infestation.

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